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ABSTRACT

This manual was develcped for use at workshops designed to introduce the fundamentals of water treatment plant operations. The course consists of lecture-discussions and hands-on activities. Each of the fourteen lessons in this document has clearly stated behavioral objectives to tell the trainee what he should know or do after completing that topic. Areas covered in this manual include: water bacteriology, ground water supplies, water filtration, chlorination, records, safety, and selected tests. A glossary of terms is included for reference. (CS)

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BASIC WATER TREATMENT OPERATION

1976

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Ministry of the Environment
Ontario

The Honourable George A. Kerr, Q.C., Minister

Everett Biggs, Deputy Minister

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BASIC WATER TREATMENT OPERATION

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Basic Gas Chlorination Workshop

Basic Sewage Treatment Operation

Surface Water Treatment Workshop

Activated Sludge Process Analyses & Interpretation Workshop

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INTRODUCTION

The *Basic Water Treatment Operation* course based on this manual covers five days at the Ministry of the Environment training facilities. The course consists of lecture-discussions and hands-on training in water treatment plant operations.

The principal objective of the course is to introduce the operator to the fundamentals of plant operations. The lesson objectives are clearly indicated at the beginning of each topic, and tell the operator what he should know or do after having covered that topic. In order to successfully complete this course, an overall average of 70% is required.

This is a working course in which each person will be expected to take an active part in subject discussions and to acquire as much practical knowledge as possible from the lectures and demonstrations presented during the course.

The Training and Certification Section wishes to acknowledge the contributions and/or assistance of the following Branches of the Ministry

Laboratory Services
Pollution Control
Project Co-ordination
Regional Operations

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SUBJECT:

WATER CHARACTERISTICS

TOPIC: 1

Water Bacteriology

OBJECTIVES:

The trainee will be able to

1. Understand the need for the production of the highest quality of water.
2. Recall the sources of bacteria in the water.
3. Recall the nature and size of bacteria.
4. Give the reason for the use of "indicator" bacteria.
5. Name 2 techniques for lab examination of samples to determine bacteriological quality.
6. Determine the minimum number of samples required and their frequency for distribution systems and for sources.
7. Demonstrate the correct Bacteriological Sampling Procedures.

BACTERIOLOGICAL CHARACTERISTICS

GENERAL

The job of keeping our drinking water safe has become a vital and increasingly difficult task. The war against pollution is only beginning. Municipalities still discharge untreated or partially treated sewage into the streams, and industry aggravates the problem by dumping an ever-changing variety of chemical contaminants.

The water works, and particularly those in the larger and more populated areas, are now confronted with problems that did not exist until a few years ago. If the water treatment works are to function properly, it is essential that their personnel know the sources of contamination that are or may become a danger to the quality of the water in their plant. The amount of close supervision required in operating a plant is materially increased in those areas where known sources of contamination are present.

Sources of industrial waste pollution as well as upstream sewage treatment plants should be known to the personnel of water works plants. An ever-changing variety of chemical and other waste discharges are reaching water works plants. As a result, most water works in industrial areas have some type of waste control treatment available. Radiological, anionic detergent, pesticide, phenolic and other organic wastes from industrial sources and from land run-off have brought new problems that are often difficult to solve. Industries are sometimes located extremely close to water works intakes, increasing the need for careful supervision in the water works plant.

While some analytical results have more importance than others, all have certain limiting values established to protect the health of the individual and the well-being of the community. These limiting values, or "Drinking Water Objectives", will be discussed with a view of their role in

attaining the above goals. These objectives were formally adopted by the former OWRC in 1964 and updated by amendment in 1967. The discussion will be divided into three sections: *bacteriological* (Topic 1), *physical* and *chemical* characteristics (Topic 2).

IMPORTANCE OF AN ADEQUATE BACTERIOLOGICAL SAMPLING PROGRAM

Communities have been relatively free of attack for generations but the possibility of a water-borne epidemic still exists. Periodically over the past few years, epidemics related to contaminated water supplies have been reported. For example, in *November* and *December* of *1959*, the community of Keene, New Hampshire, experienced a typhoid epidemic. The source of the infection was finally traced, after considerable investigation, to the Keene water supply. This community's water supply consisted of an unspoiled mountain watershed and a good, slow sand filter treatment plant. All of these factors, combined with careful water distribution practices, would indicate that the consumer was receiving a safe quality water. Yet overnight the water system turned into a distributor of the organisms of deadly typhoid fever.

A curious combination of circumstances led to the typhoid infection. A wood cutter, working in the watershed area without authorization, was discovered to be a typhoid carrier. His waste had been washed into the city's water during unusual flooding in *October*.

The epidemic at its height affected 19 people and was known to have taken the life of one person. The city officials were suddenly made aware that the city was in the business of producing a product - and they had a legal and moral responsibility to guarantee its safety. The Council was faced with the alternatives either of paying $67,000 in settlement of claims or allowing these claimants to sue the city. One attorney estimated that the costs of going to court could have risen as high as one-half million dollars ($500,000).

For at least a decade prior to the epidemic local health and water authorities, the city's consulting engineer, and the State Board of Health, had all recommended the installation and continuous operation of chlorination facilities. The City Council repeatedly denied the requests. The result: Keene paid several times the cost of the installation and operation of chlorination facilities, and derived no benefits from it. Further, the Water Department suffered a considerable loss of face.

This example points out that there will always be a need for continued responsible supervision at any water treatment plant to ensure that the quality of the water will not be affected and that there will be no return to the water-borne epidemics of another era. The first public health requirement in water works treatment is responsible supervision to assure proper standards in maintaining water quality.

BACTERIA IN WATER

General

There are many sources of bacteria present in any body of water (see Figure 1-1). Many of them make up the "normal flora" of the water, whilst others may enter the water by being washed off vegetation, soil, farmlands, etc., or by sewage plant and sewer effluents. In water treatment, the bacteria which are the most important grow and are excreted in the intestinal tract of man and animals; the "pollution cycle" shows why this is so.

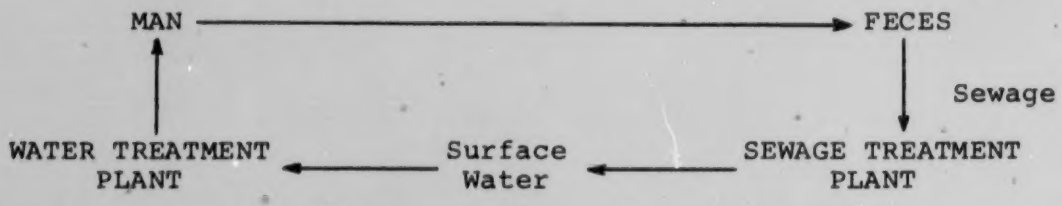
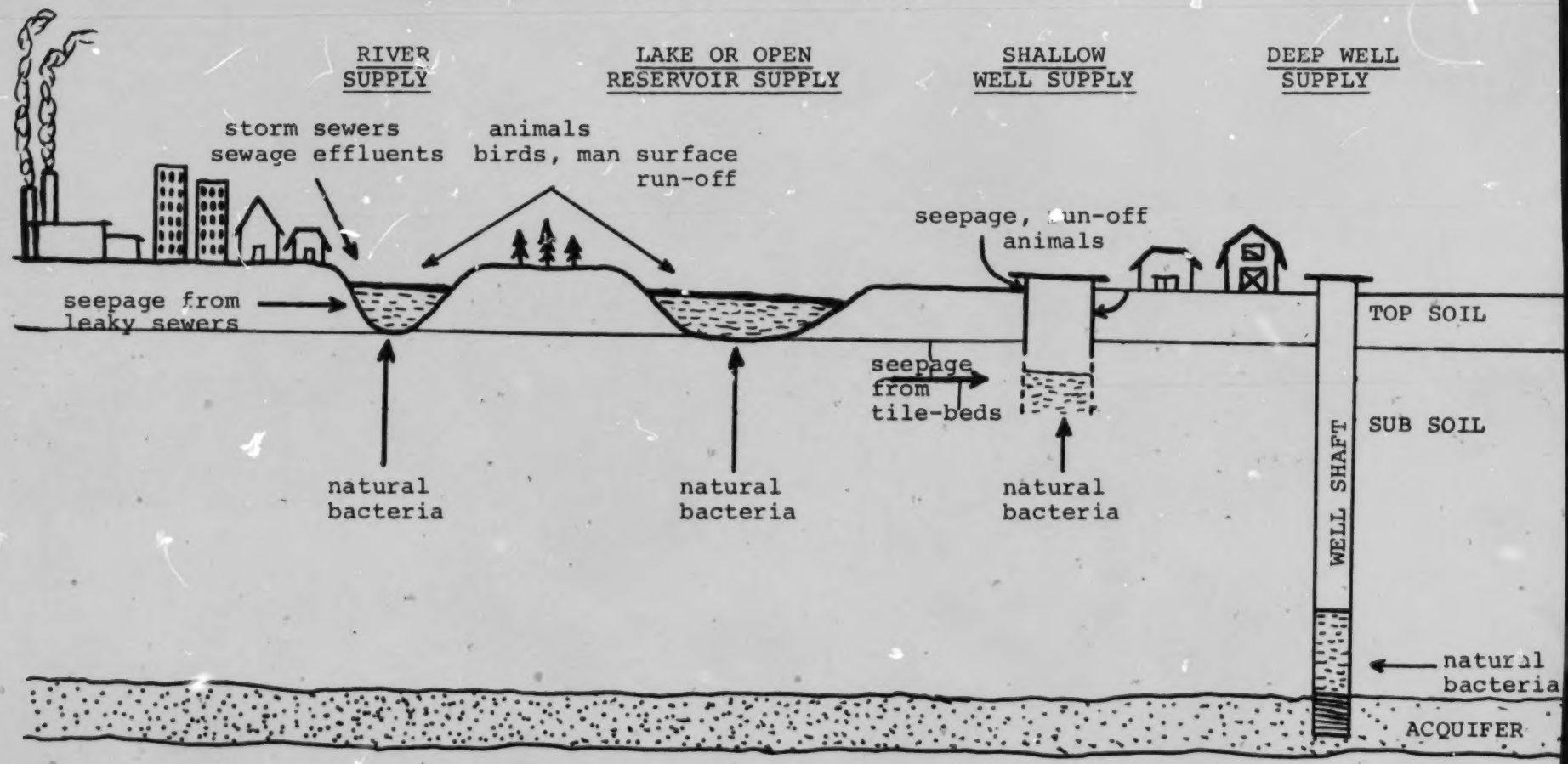


FIGURE 1-1

SOURCES OF CONTAMINATION OF WATER SUPPLIES



In the intestinal contents of man and animals some bacteria are normal flora. One group of these is the "coliform group", made up of total coliforms and fecal coliforms; another kind are the fecal streptococci; Pseudomonas and Clostridia are other kinds. All these kinds are non-pathogenic and always present in the intestinal contents.

Persons or animals infected with the so-called "enteric diseases" (typhoid, dysentery, cholera, etc.) carry and excrete millions of the disease-producing bacteria, along with the normal intestinal flora. These bacteria may gain access to the surface or well water (as outlined in Figure 1-1), which is used for drinking. If the water is consumed untreated, or improperly treated, an epidemic of the enteric disease could result.

Nature of Bacteria (Figure 1-2)

Bacteriology deals with the study of organisms known as bacteria; bacteria are a large group of microscopic organisms, widely distributed in nature, in air, water, soil, animals, plants and dead organic matter.

Size

Bacteria are one-celled and may be seen only with the aid of a microscope; they are viewed, normally only after some staining procedure, using a magnification of about 1,000 times. Their size range is from about 0.5 μ to 6 μ or 7 μ, but most are from 1-3 μ (1 μ = 1/1,000 mm).

Algae, on the other hand, can be examined using a magnification of only 100 to 200 times, and they are green-coloured because they contain chlorophyll.

Shape

There are only two basic shapes of bacterial cells:

1. Sperical forms called cocci
2. Rod-shaped forms called bacilli

although there are variations in the two basic shapes, such as filaments or bean-shaped cocci, etc.

Figure 1-2 NATURE OF BACTERIA

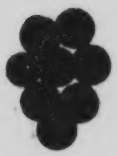
Size and Shape

Scale: ¼" = 1μ = $\frac{1}{1000}$ mm

COCCUS FORMS

Single

Chain
e.g. Streptococcus



Clump
e.g. Staphylococcus

uniform size 1μ diameter

BACILLUS FORMS

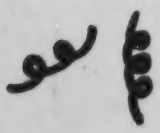
Single

Chain
e.g. Streptobacillus

Clump
e.g. Typhoid Bacillus

.3 - 1.5μ wide 1.5 - 8μ long

SPIRAL FORMS



e.g. Leptospira

.2 - .75μ wide 5 - 25μ long

FOR COMPARISON

ALGAE

e.g. Chlorella

4 - 5μ diameter

Arrangement

The bacterial cells may either be found singly, or may be attached to one another to form chains or clumps of cells; some kinds of bacteria are capable of independent movement.

Reproduction

Bacteria can multiply, usually very rapidly, by one cell splitting into two. The speed of multiplication depends greatly on environmental conditions; for example, an increase in temperature usually results in an increase in the speed of multiplication.

The various kinds of bacteria are recognized by:

1. The shape and arrangement of the cells.
2. Their metabolic properties - the food which they use and how they use it.
3. Their pathogenic properties - whether or not they produce disease in man or animals.

Bacteria are found everywhere, and the kinds and numbers vary from place to place, depending upon the environmental conditions. Some kinds of bacteria are always present in certain places; the common occurrence of one or more kinds of bacteria in a particular place is described as the "normal flora" of that place or environment. Thus, E coli is a kind of bacterium that is always found in the intestine of man, and is part of the "normal flora" of the intestine.

The great majority of bacteria are harmless to man, and perform a great number of useful functions e.g. the formation of compost. Only a few kinds are harmful to man, and those which are important in potable water production will be considered. The way in which they can gain entry to a water supply, and the steps that must be taken to eliminate them, will be discussed.

WATER TREATMENT

Since it is difficult to prevent the entry of pathogenic bacteria into a drinking water source, the water must be treated to destroy the pathogenic bacteria before it is delivered to the consumer. At first, treatment of water supplies was begun to prevent the spread of waterborne diseases. Chlorination was introduced in 1910, and was soon followed by additional treatment to produce water free from suspended solids, colour, and unpleasant tastes and odours. Coagulation, flocculation, sedimentation by storage, and filtration, which remove particulate matter from raw water, also remove bacteria. Certain bacteria, however, will remain in suspension so chlorination (or in some places, ozonization) is required to produce a water safe for drinking. *It is important to understand that bacteria can be protected from chlorine by particulate and organic matter, and badly treated or impure waters with high turbidities cannot be completely disinfected by chlorination.* When used as a final process, chlorination should be regarded only as an *additional* safeguard. It should be applied to waters which are clear and of good organic quality.

To destroy bacteria effectively, three things are important:

1. The amount of chlorine added.
2. The contact time allowed between the chlorine and bacteria.
3. The amount of protective particulate matter present in the water.

Because the efficiency of the chlorine process (disinfection) can vary, due to many reasons e.g. breakthrough of particulate matter, change in pH of the incoming water, an increased pollution load, etc., the finished water must be monitored bacteriologically. Such monitoring is designed to ensure that the disinfection stage was sufficient to kill all pathogens.

Coliforms are normal flora in the intestine, and they are also more resistant to chlorine than the bacteria that cause enteric disease. If all the coliforms are eliminated in the disinfection process, then all the disease bacteria have also been destroyed; where coliforms can still be found, some disease-producers may also have survived. So, when the coliform group of organisms is present, the water has not been treated properly to destroy all the pathogenic bacteria; the water must be considered as unfit to drink until the treatment has been improved. The coliform group is thus used as an indicator by which the efficiency of the water treatment can be determined. Other indicator bacteria are also being used on a large scale, as tests for them are perfected.

This indirect, indicator test is used because analysis for the coliform indicator bacteria is faster, easier and safer to perform than direct analysis for the disease producers.

TESTING PROCEDURE

Coliforms and other indicators may be tested for by any one, or all three of the following methods:

1. *The Presence/Absence Test* (P/A) shows only the presence or absence of a bacterial group in 50 or 100 ml of sample but not how many there are. It is used for coliforms and also fluorescent pseudomonads and clostridia.

   This method is presently being used on nearly all municipal water samples submitted to the Ministry Laboratory. The test offers a distinct advantage over others since the results are known within 18-24 hours. If there is a presence of bacteria, other tests are conducted to determine the types. The test on treated water or distribution samples should be *absent* of bacteria.

2. The *Membrane Filtration Test* (MF), is often run in conjunction with the P/A test, so that the number of coliform organisms in a sample can be counted. This is normally used in the routine analyses of raw and treated water, and can be used to count fecal streptococci and fecal coliforms.

3. The *Most Probable Number Test* (MPN). This test allows a statistical calculation of the number of coliform organisms present in a water sample. It is useful where the MF procedure cannot be used, such as for turbid water and sewage, which would block millipore filters.

For all practical purposes, the results from the MPN and MF tests are comparable. There is, however, a slight difference in the interpretation of the significance of actual numbers of coliforms indicated in each 100 millilitre (ml) portion. None of the samples having coliform organisms should have an MPN index higher than ten per 100 ml. In the MF technique none of the coliform counts should be higher than four per 100 ml.

No bacteriological analysis of water, however exact, can take the place of a complete knowledge of the conditions at the sources of supply and throughout the distribution system. Every water supply should be regularly inspected from source to distribution taps, and sampling should be repeated under various seasonal conditions, especially after heavy rainfall. It should be emphasized that when sanitary inspection indicates a water, as distributed, to be subject to pollution, the water should be considered suspect irrespective of the results of bacteriological analyses of water leaving the treatment plant.

Frequency of Sampling

Contamination is often intermittent and may not be revealed by analysing a single sample. A single sample shows only the conditions at the time of sampling; a satisfactory result does not guarantee that conditions will remain the same. Therefore, a series of samples taken regularly over a period of time is required. See Appendix A for Sampling Procedures.

The minimum number of samples to be collected and the frequency of sample collection from a *DISTRIBUTION SYSTEM* shall be determined from the following table:

Table 1-1 Frequency of Sample Collection

Population Served	Minimum number of Samples per month	Minimum Frequency of Sampling Intervals
Up to 100,000	8 + 1 per 1,000 of population	weekly
Over 100,000	100 + 1 per 10,000 of population	daily

The number of samples determined with the use of the above table shall not include plant effluents whether treated or otherwise.

Plant samples should be taken with at least the same frequency as the distribution samples indicated in Table 1-1.

In systems utilizing surface water or treated ground water, samples shall be taken and analyzed from the raw water source and the point at which treated water enters the distribution system with at least the same frequency as that for the distribution system. In addition, there should be several checks on the chemical disinfection process each day.

In systems utilizing untreated ground water, samples shall be taken and examined not less than once per week from

the source and all points at which water enters the distribution system.

The total number of samples collected monthly may consist of those examined by the Ministry, other government laboratories, water works authorities or even by commercial laboratories, if the analytical results are acceptable to the Ministry. Special samples shall not be included in the total number of samples required above.

CONTAMINATION LIMITS

Water used by a community for consumption and other domestic purposes should be piped and adequately treated to render it free from disease-producing organisms. It is reasonably certain that disease organisms are absent if no pollution indicator bacteria are found during examinations of 100 ml samples. Hazardous quality indicator organisms which include the fecal coliform and fecal streptococcus groups and pathogenic organisms such as *Pseudomonas aeruginosa* and *Staphylococcus aureus* should be completely absent from drinking water. It should also be relatively free from coliforms, *Aeromonas* bacteria and *Clostridium perfringens*, which indicate poor water quality or deteriorated conditions in the water treatment plant or distribution system. *When a minimum of two distribution system samples of 100 ml are examined each week, no sample should show the presence of fecal coliforms or fecal streptococci, or pathogens, such as Pseudomonas aeruginosa and Staphylococcus aureus, or a density of five or more coliform bacteria per 100 ml.*

If any of these limits are exceeded, immediate collection and analysis of special samples from the affected and adjacent locations should be initiated, together with an investigation by the operating authority of the cause of their presence.

If the results of these special samples also exceed the above limits immediate chlorination should take place to insure a total chlorine residual of 0.5 mg/l or a free chlorine residual of 0.2 mg/l at the end of the distribution system; and if circumstances warrant, the immediate issuance of a boil-water order should be made. Thorough resampling and analysis of the entire water system should immediately begin and continue until the limits described above are not exceeded.

When coliform bacteria are present at levels below 5 per 100 ml, they should not be detected in more than 5% of the monthly samples, nor should such organisms as Aeromonas or Clostridium perfringens be detected in more than 10% of the monthly samples. If the limits are exceeded, and inspection of the water works and distribution system should take place along the sufficient special samples to determine the cause for the limits being exceeded. A special sampling program should continue until acceptable limits are obtained.

Special samples collected as the result of an adverse bacteriological sample shall be considered additional to the total number required to be collected by a municipality for assessment of its water quality.

INTERPRETATION OF RESULTS

The interpretation of the routine bacteriological reports is perhaps the most important aspect. Results are usually expressed as the number of bacteria present per 100 ml of sample. P/A tests are reported using the words "present" or "absent".

Water delivered to the consumer ("finished" water) is expected to conform to certain limits and objectives. Where some bacteria reach undesirable levels, the pattern of the results can sometimes be used to decide the corrective action to be taken. See Table 1-2.

Coliforms are found in the intestine, but can also occur on soils and vegetation. *Fecal coliforms* form a subgroup within total coliforms but, as indicated by their name, are found *only* in human and animal fecal waste; since they die out more rapidly than coliforms, their presence should be considered as a sure indication of recent fecal pollution, calling for immediate action. The repeated presence of coliforms, in the absence of fecal coliforms, may indicate the growth of these bacteria on organic materials in the pipe or on debris, and investigation should be made into possible sources.

Fecal Streptococci (enterococci) are normally found only in situations where fecal pollution has occurred. They are used as indicators of pollution in the same way as fecal coliforms, and their isolation is especially useful where coliforms are present, but fecal coliforms cannot be found. They are more resistant to chlorination than coliforms and tend to survive longer. Absence of these bacteria shows that disinfection has been adequate.

Pseudomonas aeruginosa is a potential pathogen which occurs in sewage. Since it shows some resistance to chlorination, there is growing pressure to include a test for it and other fluorescent pseudomonads, in routine examination of potable water. As with the fecal streptococci, the appearance of pseudomonads may indicate that the chlorine dosage is too low and a correction is necessary.

Clostridia are a group of organisms which are again mainly used as indicators of fecal pollution, since they are present in sewage and manure. However, these organisms produce very resistant bodies called spores; on account of these, the bacteria can survive in water long after all other indicator organisms have disappeared. These indicators are useful in water supplies that are not sampled frequently. In these cases, chance sampling may give good coliform results, but the water could be dangerously contaminated at intervals in between. Clostridia would probably be isolated

in these circumstances and would indicate a need for closer surveillance. The spores are not destroyed by normal chlorination practices, and repeated positive clostridial tests show that treatment was inadequate before final chlorination (e.g. in filtration).

Treating water supplies properly and effectively not only ensures freedom from pathogenic organisms, but also yields beneficial side effects. A finished water entering the distribution system with a turbidity of 1 unit or less and chlorine residual of 0.3 ppm will meet bacteriological standards, and organic material and debris will not enter the lines. *Every effort should be made to achieve these levels.* Where debris enters the lines, bacterial growth and slime formation can occur, with taste and odour and red water problems developing. Correct pH control and/or treatment for the presence of iron will prevent the deposit of rust and iron materials in the line.

A conscientiously applied treatment will prevent the transmission of water-borne disease, deliver to the consumer a clear, palatable product, and maintain a trouble-free system.

Table 1-2 BACTERIA INDICATORS OF SEWAGE CONTAMINATION IN WATER TREATMENT

	Total	Fecal Coliform	Fecal Streptococci	Pseudomonas Aeruginosa	Fluorescent Pseudomonads	Clostridia
Test	MF	MF	MF or P/A	P/A	P/A	P/A
Reported	Numbers/ML	Numbers/ML	Numbers/ML	+ or -	+ or -	+ or -
Maximum Allowable Limit	5/100 ml in monthly samples	Absent	Absent	Absent	Few	10% samples positive
Source	Sewage, Soil Vegetation	Fresh sewage	Sewage	Sewage	Soil, Water Sewage	Old Sewage Manure
Indication	a) Possible contamination with sewage	Definite contamination with fresh sewage	Definite contamination with sewage	Improper treatment	Improper treatment	Improper treatment prior to chlorination
	b) Improper treatment		Improper treatment			
	c) Growth in system					

I-16

REFERENCES

The following references are provided for those who may wish to add to their library. These texts are not specifically confined to the bacteriological section but contain information applicable to any section of the course.

1. Water Quality and Treatment. A Handbook of Public Water Supplies. 3rd Edition. Prepared by the American Water Works Association, Inc., McGraw-Hill, Book Company.

2. Water Treatment and Examination. Edited by W. S. Holden, 1970. Published by Williams & Wilkins.

3. Ministry of Environment Drinking Water Objective, 1976.

SAMPLING PROCEDURES

The water sample must represent only the condition of the water *at the time of collection*, so the following precautions are necessary. *Reliable results depend on using proper sampling techniques and the necessary care when collecting the samples.*

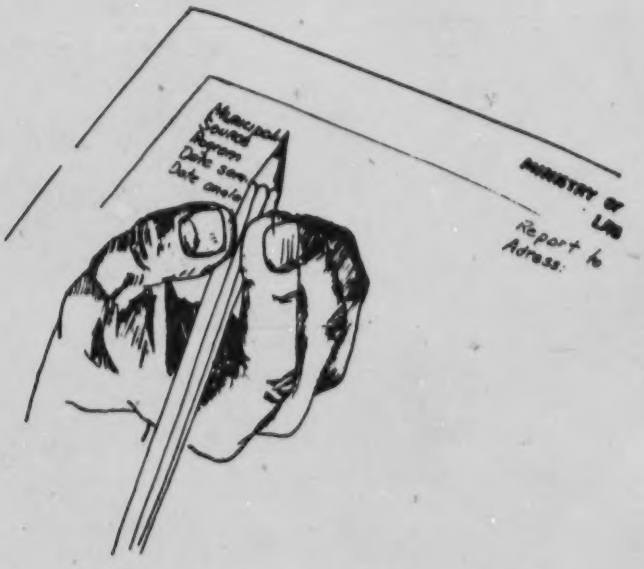
1. The bottles must be sterile (bacteria free), obtained from the Shipping and Receiving Department of the Ministry's laboratory.
2. The sampler's hands should be washed thoroughly and dried before handling the bottle, to be sure that no bacteria are introduced from that source. When the bottle cap is removed, the inside edges of the cap and the mouth of the bottle must not be handled, and the cap should not be put down.
3. From a tap, the water should be allowed to run freely for at least *two minutes before the bottle cap is removed.* When samples are taken from a well, river, stream, lake or open tank, the bottle should be submerged below the surface. Sampling devices, such as a copper wire around the neck of the bottle, should be flame-sterilized before being used. In all cases, the bottle should be filled so as to leave enough air space for proper mixing before analysis.
4. For sampling water that contains chlorine, a bottle containing sodium thiosulphate should be used. The thiosulphate neutralizes any remaining chlorine and prevents it from continuing to kill off any remaining bacteria during shipment of the sample.

Figure 1-3 SAMPLING PROCEDURES

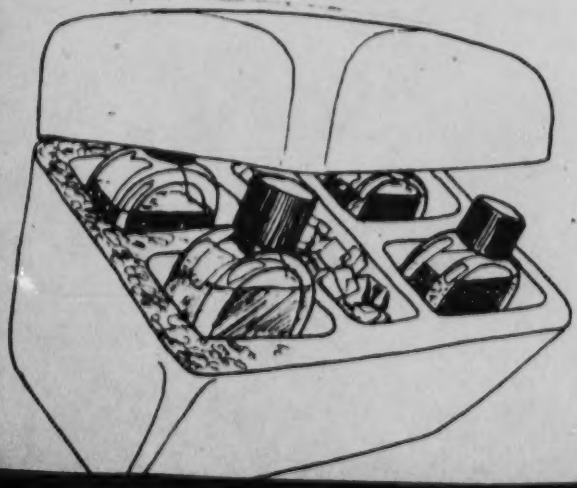
1. Wash hands thoroughly.

2. Dry hands well.

3. Allow tap to run for a few minutes. Fill bottle, hold cap as shown.



4. Fill out Sample Report in full.



5. Ship Samples packed in ice.

5. The sample report should be filled out in full, giving all the particulars of the sample, and information which may assist the analyser in the selection of the best possible combination of tests for the purpose.

6. The water samples should be shipped to the Ministry laboratory immediately, and should arrive within 24 hours. Refrigeration is desirable, since an increase in temperature in the sample may encourage multiplication of the bacteria and result in an erroneously high count. Special containers are now available for maintaining low temperature during shipment.

Bacteriological samples over 3 days old are not tested as there is too much change in population and a completely false picture of the water at the time of sampling could be obtained.

The responsibility for taking the required number of samples lies with the operating authority, whether it be a municipality or an individual who owns a private water supply.

SUBJECT:

WATER CHARACTERISTICS

TOPIC: 2

Physical and Chemical Characteristics

OBJECTIVES:

The trainee will be able to:

1. Recall the physical characteristics of water which waterworks operators must recognize.

2. Recall the problems associated with various chemical substances in water.

3. Describe the following characteristics of water:

   a) acidity,
   b) alkalinity
   c) hardness
   d) hydrogen sulphide
   e) Turbidity

4. Recall causes/sources of taste and odour problems.

PHYSICAL CHARACTERISTICS

Physical tests do not measure the safety of a water supply, but they do give an indication of its acceptability to the consumer. This is why the objectives adopted by the Ministry to govern the physical characteristics of the water are not as strict as those required for bacteriological control. The physical qualities which concern water works operators are:

1. *turbidity*
2. *colour*
3. *taste and odour*

Another physical characteristic measured, but uncontrollable is (4) *temperature*.

Substances producing turbidity are often inorganic while those causing taste, odour and colour are generally organic compounds.

Turbidity, colour and taste and odour requirements can be attained by properly designed and operated treatment plants and distribution systems. Failure to meet the requirements indicates either inadequate treatment facilities or improper operation of the system.

Turbidity

Turbidity can be defined as matter suspended in water causing a cloudy undesirable appearance.

If left untreated, most of the smaller turbidity particles would pass through a standard filter while the larger turbidity particles would soon plug the surface of the filter causing short filter runs.

Sedimentation, even in enormous reservoirs would only partially reduce the amount of suspended matter in the water. The following chart gives you some idea of the time required.

TABLE 2-1

SETTLING TIME - PARTICLES

Diameter of Particle Microns	Order of Size	Approximate Time Required to Settle 1 Foot
100	Fine Sand	38 sec.
10	Silt	33 min.
1	Bacteria	55 hr.
0.1	Colloidal Particle	230 days

25,400 microns = 1 inch

Turbidity should average not more than 1 unit. At levels approaching 10 units, the water appears cloudy. Plants with complete treatment should routinely produce water which meets this objective. Ground water supplies will normally meet the objective without the need for treatment.

Colour

The occurrence of organic colour in water attributed to complex organic compounds formed when the water leaches the colour out of disintegrating woody and vegetable materials in the water is made up of a number of organic compounds which are usually categorized as "humic substances". The general properties of "humic substances" are:

1. Size in the range of 0.003 to 0.02 microns. One can appreciate how small this is as the colloidal turbidity particles are in the range of 0.05 to 0.15 microns. (25,400 microns = 1 inch).
2. The colour particles are negatively charged due to the chemical groups attached to the humic substances.
3. The magnitude of their chemical charge is dependent on the pH of the water.

When determining the colour content of water, a difference between straight raw water colour and a filtered water colour may be noticed. The difference is due to the non-coloured suspended matter that interferes with the colour equipment. The colour of the raw water is known as the *apparent* colour. The colour of the water having been centrifuged and decanted is known as the true colour.

Colour levels commonly encountered in Ontario vary from:

0 - 5	Hazen	Great Lakes
30 - 60	Hazen	Ottawa River & Southern Ontario Rivers
100 - 150	Hazen	Northern Ontario Lakes & Rivers

Of course, there are exceptions to this guide but generally speaking most highly coloured waters are found in Northern Ontario.

Colour removal is possible using alum coagulation, sedimentation and filtration. Colour should average not more than 5 (apparent colour) units.

Taste and Odour

The presence of any unusual tastes in a public drinking water is likely to arouse some public reaction. The average consumer tends to associate them with impure or poor quality water even though that water may be sparkling clear and safe to drink. If any unusual tastes continue to persist in the water, he is likely to reject it and attempt to seek a more palatable water from another source which may not be sanitary and considered desirable for human consumption.

Taste and odour control is an important part of the water treatment process. Because the consumers can detect and react to any sudden changes in the palatability of the water, the waterworks operator should be prepared to deal with these conditions as quickly as possible.

The senses of smell and odour are closely related. The complaints of objectionable tastes in water supplies are usually associated with odour. There are only four true taste sensations - salt, sweet, sour and bitter. All other apparent sensations commonly referred to as tastes are actually odours even though the sensation may not be experienced until the substance has actually been placed in the mouth.

It is almost impossible to determine and classify the different types of odours that can be experienced. Table 2-2 on page 2-6 gives a qualitative description of some of the more common odours found in water supplies. It can be used as a guide to classify the type and determine the source of odour.

Tastes and odours in water supplies may result from any one or a combination of conditions. They are usually caused by the presence of dissolved gases and organic substances. In some cases, inorganic compounds such as those of mineral and metallic salts may impart tastes to the water at very low concentrations. However, organic substances are likely to be responsible for the presence of odours. Sources of material causing taste and odour problems may be:

1. Dissolved gases mainly hydrogen sulphide are found in well supplies.
2. Biological growths such as algae, protozoa and slimes.
3. By-products of decaying algae and vegetation.
4. Contaminants from sewage effluents, and surface runoffs.
5. Contaminants from industrial waste discharges.
6. Growths of nuisance organisms in the distribution system.

7. Contact of water with painted surfaces such as bituminous linings of water pipes and storage tanks.

8. Excess quantities of chemicals such as chlorine and sodium chlorite used in the water treatment process.

The variation in tastes and odours caused by algae has a wide range. The odours may be classified as follows:

1. Aromatic Odour - These odours are very often described as a particular flower or vegetable. Organisms in small numbers can produce these odours.

2. Fishy Odour - These odours are often produced by the same algae that produce the aromatic odours. The organisms are usually present in much larger numbers.

3. Grassy Odour - This odour is very common when the green algae are present in large numbers.

4. Musty and Earthy Odour - The musty odour in some waters is very often encountered in the presence of certain blue-green algae.

The control and prevention of many tastes and odours caused by algae may be with the use of:

1. Chlorine

2. Carbon

3. Potassium Permanganate

4. Microstraining

The Ministry objective for odour is a threshold odour number not greater than 3 and the taste should not be objectionable.

TABLE 2-2- GUIDE FOR QUALITATIVE DESCRIPTIONS OF ODOURS

CODE		NATURE OF ODOUR	DESCRIPTION (Odours of:)
A		Aromatic (spicy)	camphor, cloves, lavender,
	Ac	cucumber	lemon, *Synura*
B		Balsamic (flowery)	geranium, violet, vanilla
	Bg	geranium	*Asterionella*
	Bn	nasturtium	*Aphanizomenon*
	Bs	sweetish	*Coelosphaerium*
	Bv	violet	*Mallomonas*
C		Chemical	industrial wastes or treatment chemicals
	Cc	chlorinous	free chlorine
	Ch	hydrocarbon	oil refinery wastes
	Cm	medicinal	phenol and iodoform
	Cs	sulfuretted	hydrogen sulfide
D		Disagreeable	(pronounced unpleasant)
	Df	fishy	*Uroglenopsis, Dinobryon*
	Dp	pigpen	*Anabaena*
	Ds	septic	stale sewage
E		Earthy	damp earth
	Ep	peaty	peat
G		Grassy	crushed grass
M		Musty	decomposing straw
	Mm	moldy	damp cellar
V		Vegetable	root vegetables

Ref: Standard Methods for the Examination of Water and Wastewater, 12th Edition, p.306

Temperature

Very little can be done about water temperature. The most desirable range is from 4°C to 10°C. Higher temperatures make water less palatable and reduces its suitability for air conditioning purposes. Temperatures above 27°C are unsuitable and above 32°C render the water unfit for public use.

CHEMICAL CHARACTERISTICS

Normally, analyses for chemical constituents are only needed twice a year. But if the supply is suspected of containing undesirable materials, periodic determinations for the suspected toxicant or material should be carried out more frequently (every month for example). On the other hand, where experience, examination and results indicate that particular substances are consistently absent from a water supply or are below levels of concern, then, with the approval of the Ministry, semi-annual examinations *for these substances* may be omitted.

Limits for Chemical Constituents

The chemical constituent concentrations in water may be broken down into two categories:

1. Those concentrations which can be tolerated if a better source in not available.
2. Those concentrations which constitute grounds for rejection of a supply. Because of the rapidly changing field of complex chemicals it has become important that the objectives for chemical constituents be reviewed regularly.

The chemical substances shown in the following table should *NOT* be present in a water supply in excess of the listed concentrations where, in the judgment of the Ministry, other more suitable supplies are or can be made available.

TABLE 2-3 TOLERABLE LIMITS OF CHEMICALS IN WATER

Substance	Concentration mg/l or ppm
Alkyl benzene sulphonate (ABS)	0.5
Arsenic (As)	0.01
Chloride (Cl)	250.0
Carbon chloroform extract (CCE)	0.2
Cyanide (CN)	0.01
Fluoride (F)	2.4
Iron (Fe)	0.3
Manganese (Mn)	0.05
Nitrate (NO_3)	45.0
Phenols	0.001
Sulphate (SO_4)	250.00
Total Dissolved Solids	500.0
Zinc (Zn)	5.0

The presence of substances in excess of the concentrations listed below shall constitute grounds for rejection of the supply.

TABLE 2-4 MAXIMUM ALLOWABLE LIMITS OF CHEMICALS IN WATER

Substance	Concentration mg/l or ppm
Arsenic (As)	0.05
Barium (Ba)	1.0
Cadmium (Cd)	0.01
Chromium (Cr^{+6})	0.05
Cyanide (CN)	0.2
Fluoride (F)	> 2.4
Lead (Pb)	0.05
Selenium (Se)	0.01
Silver (Ag)	0.05

Problems Associated with Chemical Constituents

The chemicals that occur most frequently and create significant problems in the distribution system as well as for the consumer are discussed first.

1. Iron (Fe)

   An upper limit of 0.3 mg/l for iron has been adopted as an objective.

   Iron in water can be highly objectionable for either domestic or industrial supplies. The domestic consumer complains that iron imparts a brownish colour to plumbing fixtures and laundered goods. In addition, iron appreciably affects the taste of beverages.

   Added problems often develop in the distribution system as a result of the growth of iron bacteria, which thrive in the presence of iron. These bacteria present staining problems by converting iron in solution into red, insoluble matter. Watermains may become fouled by the masses of stringy growths associated with iron bacteria.

   Iron may be removed by ion exchange, aeration, settling and filtration and iron bacteria may be controlled by chlorination.

2. Manganese (Mn)

   Manganese presents much the same nuisance conditions as iron. It is difficult to remove this chemical and it is recommended that concentrations not exceed 0.05 mg/l.

3. Nitrate (NO_3)

   This Ministry has adopted the objective of 45.0 mg/l of nitrate (NO_3). In areas where the nitrate content

of water is known to be in excess of the listed concentration, the public should be warned of the potential dangers of using the water for infant feeding.

Serious and occasionally fatal poisonings of infants have occurred following ingestion of well waters containing high levels of nitrate. Wastes from chemical fertilizer plants and field fertilization may be sources of such pollution.

Nitrate poisoning seems confined to infants during their first few months of life. The nitrates give rise to infantile methemoglobinemia ("blue-baby" condition). It can be cured or terminated by providing nitrate-free water.

4. Sulphate (SO_4)
A recommended upper limit of 250 mg/l has been adopted.

Sulphur has a laxative effect on newcomers and casual users of waters high in sulphates. A person does, however, become accustomed to the use of these waters in a relatively short time. The taste of the water may also be adversely affected.

5. **Chloride** (Cl)
The objective for chloride has been set at an upper limit of 250 mg/l. Above this level a salty taste is apparent. Many municipalities experience higher levels of chloride with varying taste intensities. Abnormal amounts of chloride in a natural water suggests pollution probably of a chemical origin.

Although the presence of any of the following chemicals in a water source would be quite significant their

rate of occurrence is quite low. They are listed alphabetically:

1. Alkyl Benzene Sulphonate (ABS)
   The objective for ABS in water supplies has been set at 0.5 mg/l. Tests have confirmed that 1 mg/l presents an off-taste to water and at this level foaming often occurs. No apparent toxic effects were evident when tests were conducted with water containing 50 mg/l of ABS. ABS will contaminate drinking-water supplies by its disposal, as household and industrial wastes, into sources of raw water. The concentration of ABS in municipal sewage ranges as high as 10 mg/l. Such contamination may appear in both surface and ground water supplies.

2. Arsenic (As)
   The present knowledge concerning the potential health hazards associated with the ingestion of organic arsenic indicates that the concentration of arsenic in drinking water should not exceed 0.01 mg/l and concentrations in excess of 0.05 mg/l are grounds for rejection of the supply.

   The widespread use of inorganic arsenic in insecticides and its presence in animal foods, tobacco and other sources, make it necessary to set a limit on the concentration of this chemical in drinking water.

3. Barium (Ba)
   This constituent is not particularly common but the Ministry has adopted the objective that concentrations in excess of 1.0 mg/l are grounds for rejection of the supply because of the serious toxic effects of barium on the heart, blood vessels and nerves.

4. Cadmium (Cd)

Tests have shown that concentrations up to 0.01 mg/l can be tolerated, but concentrations in excess of this are considered grounds for rejection of a supply.

Cadmium is recognized to be an element of high toxic potential. Very little attention has been paid to this constituent in the past.

Seepage of cadmium into ground water from electroplating plants has resulted in concentrations up to 3.2 mg/l. Other sources of cadmium contamination in water arise from zinc-galvanized iron in which cadmium is used.

5. Carbon Chloroform Extract (CCE)

The objective for CCE is 0.2 mg/l.

The Carbon Chloroform Extract (CCE) test is a practical measure of water quality and is a safeguard against the intrusion of excessive amounts of potentially toxic material into water. It is proposed as a technically practical procedure which will provide some protection against the presence of undetected toxic materials.

The test provides an indication of organic material in the treated water. The presence of organic material shows that pollutants have not been removed in the treatment process.

6. Chromium (Cr^{+6})

Concentrations in excess of 0.05 mg/l as hexavalent chromium (Cr^{+6}) are grounds for rejection of the supply. Trivalent chromium is not believed to be of concern in drinking water supplies.

Chromium is another unnatural constituent of water supplies. It is not known to be either an essential or beneficial element in the body. Its presence indicates industrial pollution, probably caused by a plating or tannery operation.

7. Copper (Cu)

The concentration of 1.0 mg/l is the recommended objective.

Copper is an essential and beneficial element in human metabolism. It is well known that a deficiency in copper results in nutritional problems in infants. Copper imparts some taste to water and is detectable in ranges from 1 to 5 mg/l. Small amounts are *not* generally regarded as toxic; very large doses may cause sickness, and, in extreme cases may cause liver damage. When copper sulphate is used on a surface water supply for algal control, the levels of copper in the water must be closely controlled.

Copper in small amounts does not constitute a health hazard but imparts an undesirable taste to drinking water.

8. Cyanide (CN)

The Ministry objective is to reduce cyanide levels to less than 0.01 mg/l. For the protection of health, concentrations above 0.2 mg/l constitute grounds for rejection of the supply. The 0.01 mg/l concentration provides a necessary safety factor because of the rapidly fatal effect of cyanide.

9. Fluoride (F)

Where fluoride is added to the water supply, a 1.0 mg/l concentration is recommended. (A permissible operating range is 0.8 mg/l to 1.2 mg/l, as it is believed that mottling of the teeth occurs at and above this level.) Fluoride in drinking water

will prevent dental caries in children, and to a lesser degree, in young adults. When fluoride is naturally present, the concentration should not average more than 1.2 mg/l. Presence of fluoride in concentrations more than 2.4 mg/l shall constitute grounds for rejection of the supply.

Fluoridated and defluoridated supplies should be frequently sampled to determine that the desired fluoride concentration is being maintained.

10. Lead (Pb)

A concentration of lead in excess of 0.05 mg/l has been adopted as an upper limit for drinking water, and concentrations in excess of this amount are grounds for rejection of the supply.

Lead taken into the body can be seriously injurious to health, even lethal, if taken in by either brief or prolonged exposure.

11. Phenol

Undesirable tastes often result from the chlorination of waters containing extremely low concentrations of phenol. The objective for phenol has been adopted as 1 ppb (0.001 mg/l).

12. Selenium (Se)

Levels of selenium in excess of 0.01 mg/l constitute reasons for rejection of a water supply. While trace amounts of this chemical are considered to be essential to man, higher concentrations appear to be extremely toxic in a manner similar to arsenic. Surveys have shown that selenium may increase the rate of dental caries in permanent teeth.

13. Silver (Ag)

A water supply shall be rejected if it contains more than 0.05 mg/l of silver. This level was established, not because of toxic effects, but due to the unsightly permanent blue-grey discolouration of the skin, eyes and mucous membranes which may result from its ingestion. Evidence indicates that silver, once absorbed, is held indefinitely in the tissues, particularly the skin.

14. Total Dissolved Solids

High dissolved solids concentrations are associated with correspondingly high levels of sulphates and/or chlorides. An upper limit of 500 mg/l has been adopted as the objective, in order to exercise control over the taste and laxative properties.

15. Zinc (Zn)

An objective of 5.0 mg/l has been adopted.

Zinc is an essential and beneficial element in human metabolism and does not appear to have a serious effect on health. The tendencies for zinc salts to impart a milky appearance to water at 30 mg/l and a metallic taste at about 40 mg/l are the only apparent undesirable characteristics.

OTHER CHEMICAL CONSIDERATIONS

Acidity and Alkalinity

Alkalinity and acidity of water refer to the amounts of acids or bases present and are measured in mg/l. These are not to be confused with pH which is measured on an arbitrary scale from 0 to 14 pH and is a measure of chemical activity or intensity. There are no particular limits for either alkalinity or acidity and both are expressed in terms of calcium carbonate ($CaCO_3$).

Acidity is characteristic of many northern waters; alkalinity is a characteristic of waters found in southern Ontario. Acidity is not desirable in a municipal water system, but it does not normally affect the potability or palatability of the water.

Alkalinity refers to the carbonate, bicarbonate and hydroxide content of a water. It usually occurs in the form of Calcium (Ca) and magnesium (Mg) bicarbonates.

Where the alkalinity *exceeds* the hardness (see below), basic salts, generally sodium (Na) and potassium (KO) are present.

If the alkalinity is less than the hardness, then salts of Ca and Mg are present in association with sulphates, chlorides or nitrates.

Hardness

The hardness content of Ontario water ranges from less than 10 mg/l to 1800 mg/l. A preferable hardness is in the range of 90 mg/l to 100 mg/l. Above 500 mg/l the water may be considered objectionable for domestic use. Waters with hardness less than 30 mg/l are quite soft and probably corrosive.

Carbon Dioxide (CO_2)

In surface supplies the normal carbon dioxide content will range from 0.5 to 2.0 mg/l while in ground water it will range as high as 50 mg/l. A proper balance of carbon dioxide in water will ensure that the water is neither corrosive nor scale-forming.

Hydrogen Sulphide (H_2S)

Even trace amounts of hydrogen sulphide will cause water to taste and smell like rotten eggs. It is not harmful from a health standpoint and may be removed by either chlorination or aeration followed by filtration.

pH

Natural waters generally range from 5.5 to 8.6 in pH value. Waters with lower pH tend to cause corrosion and in many cases an upward adjustment to the neutral range (pH 7.0) is necessary.

Phosphate (P)

In a natural, unpolluted water, phosphates present no problems. However, because of the increased use of detergents and commercial fertilizers, phosphates are being discharged into lakes and streams in high concentrations, greatly affecting biological activities in these waters. Consequently, they exert secondary effects on water supplies, often requiring additional treatment facilities. On the other hand, complex phosphates are often introduced into sources of supply for the prevention of corrosion and scaling in water distribution systems.

Radiological Limits

The exposure of humans to radiation is harmful, and any unnecessary exposures to ionizing radiation should be avoided. Concentrations which average above the values in the following table for a period of one year, shall constitute grounds for rejection of the supply.

Radionuclides	Concentration μ μc/l
Radium - 226 (Ra^{226})	3
Strontium - 90 (Sr^{90})	10
Gross beta activity (Sr^{90} and alpha emitters absent*)	1,000

* Absent is taken here to mean negligibly small fraction of the above specific limits, where the limit for unidentified alpha emitters is taken as the listed limit for Ra^{226}.

Where the total intake of Ra^{226} and Sr^{90} from all sources has been determined, the limits may be adjusted by the Ministry so that the total intake of Ra^{226} and Sr^{90} will not exceed 7.3 micro micro-curies (μ μc) per day and 73 μ μc/day, respectively. When mixtures of Ra^{226} and Sr^{90}, and other radionuclides are present, the above limiting values shall be modified to ensure that the combined intake is not likely to result in exposure exceeding the Radiation Protection Guides recommended by the United States Federal Radiation Council.

OBJECTIVES:

The trainee will be able to:

1. Recall advantages and disadvantages of using ground water;

2. By diagram, describe the water cycle;

3. Recall the purposes for and list operating data required on a daily and weekly basis in the groundwater treatment process;

4. Describe using diagrams the most common groundwater treatment systems in Ontario;

5. Recall the purpose of:

   a) chlorination
   b) aeration
   c) filtration

   in the treatment of groundwater.

6. Recall the most common types of well failures and methods of correction.

GROUND WATER SUPPLIES

WHAT IS GROUND WATER?

Water can be considered one of the most important natural resources of this country. Although we hear a great deal about the millions of lakes and streams in Canada, very little mention is made about waters hidden beneath the land's surface. This hidden wealth is called *ground water* and actually makes up the vast bulk of our fresh water supplies.

Although ground water makes up less than 1/3 of water *used* in Ontario, most estimates place the ground water supply in excess of 80%, and all surface supplies, including the Great Lakes, at less than 20%.

Advantages to Using Ground Water:

1. Can be developed on the site; transmission piping not necessary.
2. Quality and temperature more constant.
3. Savings on storage or reservoir space.
4. Less easily polluted.
5. Economical even in small developments.
6. Often does not require treatment.
7. More widespread than surface waters.

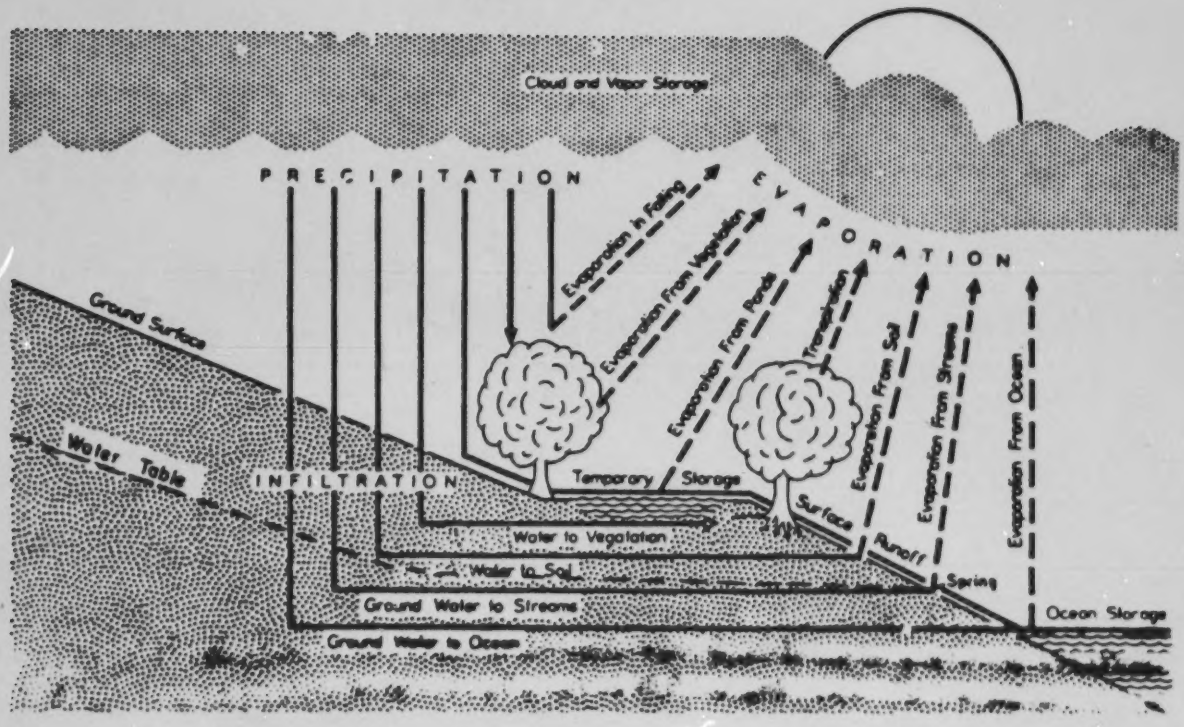


Figure 3-1 THE HYDROLOGIC CYCLE

Disadvantages to Using Ground Water:

1. Usually very hard; may have other minerals in solution.
2. If polluted, may be impossible to correct.
3. Cannot be observed directly; must be discovered and gauged scientifically.

SOURCE AND MOVEMENT

All water comes from rain and snow deposited on the earth as a part of the *water* or *hydrologic cycle*. This cycle has been called the circulatory system of the earth. Ground water is part of this cycle. (See Figure 3-1)

Moisture-laden air moving over the land masses from the oceans drops about 30 inches of precipitation in the form of rain and snow on North America every year. Of this amount, 60 to 80 percent is returned to the atmosphere by direct evaporation as it falls, by evaporation from the land surface, by evaporation from bodies of surface water, by evaporation from vegetation, and by *transpiration* from the plants which draw water up from the soil through their roots. Of the remainder, another 10 to 20 percent reaches surface-water bodies directly as surface runoff. Some of the remainder infiltrates the ground to form the soil moisture which is available to vegetation and a very small amount, probably about 10 to 20 percent, moves downward to become ground water in the saturated zone.

Water in the saturated zone moves under the influence of gravity at rates of from about five feet per day to about five feet per year. It usually reappears at the surface as a spring or discharge into a stream, lake, or ocean. This fact is readily recognized when we observe rivers and streams continuing to flow after long periods of no rainfall. The rivers are being fed by ground water which drains slowly into the river channels throughout the drainage system. Only during the more intense or long rainfall periods do appreciable quantities of precipitation run off directly to streams without passing through the ground. It is very important to keep in mind that ground water and surface water are not separate and distinct but closely interrelated.

QUALITY OF GROUND WATER

Water moving through the atmosphere and soil particles comes into contact with many soluble materials. These form chemical compounds, or salts, which are contained in solution.

Some rocks are more soluble than others. Granites, for example, are relatively insoluble but limestone, gypsum, and dolomite can be quite soluble. Over long periods of time, considerable amounts of calcium carbonate or sulphate are taken into solution from these rocks.

Ground water is usually very hard. A hardness scale in common use is as follows:

TABLE 3-1 HARDNESS SCALE

	Hardness
Soft Water	0-60 mg/l (ppm) of Calcium Carbonate ($CaCO_3$)
Medium or Moderately Hard Water	61-120 mg/l of Calcium Carbonate ($CaCO_3$)
Hard Water	121-180 mg/l of Calcium Carbonate ($CaCO_3$)
Very Hard Water	Greater than 180 mg/l of Calcium Carbonate ($CaCO_3$)
(The conversion for grains of hardness = 1 grain/Imp gal = 14.3 ppm)	

Depending on geological conditions, ground water may also contain hydrogen sulphide, salt, or iron.

The quality of ground water can be affected by careless waste disposal; ground-water supplies that are polluted may be difficult or impossible to correct.

Although we are becoming aware of the dangers of surface water pollution, "out of sight, out of mind" is still the guiding rule for buried wastes. These wastes do not disappear; they can seep downward, penetrate and contaminate the ground-water table. Here the contaminated liquids can be drawn into a pumping well which would then have to be abandoned. Many serious contamination problems can result if the practice is not prevented or properly controlled.

In the United States, some states have very serious ground-water pollution problems with large water supplies made useless due to careless waste disposal with no regard for contamination of ground water.

STORAGE

As part of the hydrologic cycle, ground water is a renewable natural resource; the amount that finally flows out on surface or is extracted by means of wells is usually replaced every year. If we assume that about 20 percent of the precipitation that reaches the earth's surface infiltrates the ground, this would mean that for every square mile of land surface, 250,000 gallons of water per day would infiltrate. This figure, however, is controlled by such factors as surface formations, soil type, vegetal cover, and ground formations. Where sand and gravel deposits are present at surface or where bedrock formations with their weathered surfaces outcrop, a maximum amount of infiltration will take place. On the other hand, surface deposits of clay or *clay till* will contribute to a greater amount of surface runoff.

Ground water is stored in the pore spaces between the sand and clay particles and in the crevices and solution channels of the rock formations. Poorly-sorted sand, gravel, silt, and clay materials (such as occur in glacial till, where large and small particles of soil are mixed together) have a smaller proportion of pore space to store water than do well-sorted materials where all the grain sizes are equal.

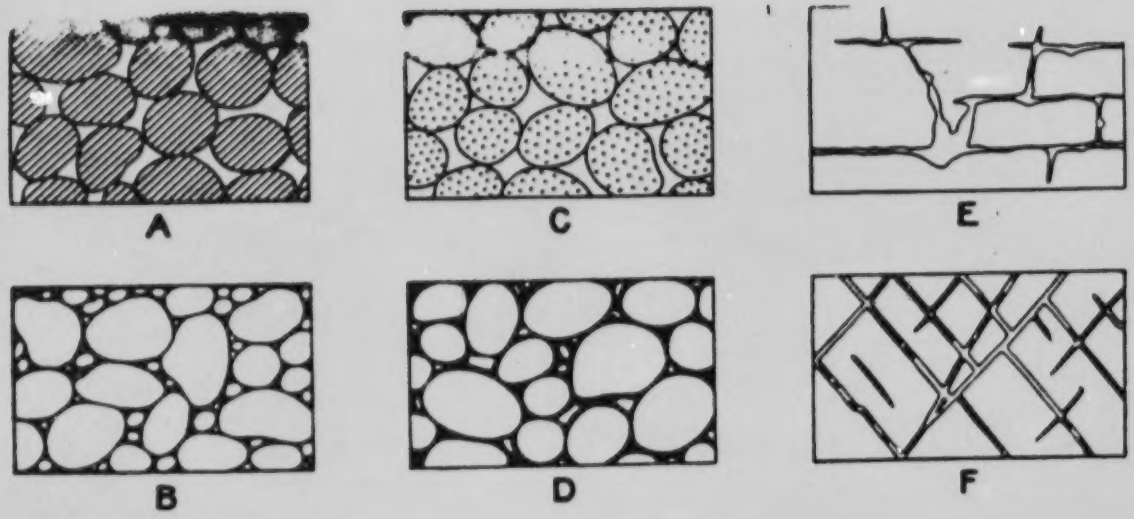
A general range in porosity of natural sediments and sedimentary rocks is given in Table 3-2. (See Figure 3-2)

TABLE 3-2

POROSITY OF NATURAL SEDIMENTS AND SEDIMENTARY ROCKS

Materials	Porosity Percent
Sandstone	4-30
Sand, Clean and Uniform	30-40+
Gravel, Clean and Uniform	30-40+
Sand and Gravel Mixed	15-25
Silt and Clay	
As Deposited	40-90
Compacted and Dewatered	20-40
Shale	1-35
Limestone	1-50

A formation may contain many pore spaces which contain a great deal of water, but if the pores are small or are not connected so water can flow freely from one pore to another, the formation may yield only a small amount of water. This introduces the second very important factor used in determining how a formation will act as a source of water. It is called *permeability* or the *ability of soil or rock to transmit fluids.* A formation such as sand and gravel or creviced limestone which has many pore spaces large enough and interconnected to allow ground water to move freely through them is called an *aquifer.*



A—Well-sorted sedimentary deposit having high porosity.

B—Poorly sorted sedimentary deposit having low porosity.

C—Well-sorted sedimentary deposit consisting of pebbles that are themselves porous; the deposit, as a whole, has a very high porosity.

D—Well-sorted sedimentary deposit whose porosity has been diminished by the deposition of mineral matter in the interstices.

E—Rock rendered porous by solution.

F—Rock rendered porous by fracturing.

Figure 3-2

Diagram showing several types of rock interstices and the relations of rock texture to porosity.

The amount of water stored in these aquifers or ground-water reservoirs has not been fully determined. The Ministry of the Environment and government agencies in several other provinces, notably Alberta and Saskatchewan, are stepping up their collection of basic data and making an inventory of ground-water conditions by means of geologic and hydrologic surveys.

The Precambrian granites and other rock types underlie 60 percent of the area of the Province, chiefly in northern Ontario. As a rule, these formations are classified as poor aquifers. Wells may obtain sufficient water for average domestic needs from joints, cracks, or fracture planes near the surface of these rocks but high-capacity wells are confined almost entirely to the sand and gravel deposits in the overburden above them making them gravel wells.

The limestones and dolomites of southern Ontario vary widely in their water yielding properties. They often make better aquifers in the southwestern parts of the Province than they do in south-central or eastern Ontario. The quality of the water is generally very hard and is often highly mineralized with sulphur compounds, particularly in the areas closest to Lakes Erie and Ontario and the St. Lawrence River.

The shale formations yield only small quantities of water but the water is much softer than that from the limestone rocks. Salty water is frequently encountered at shallow penetrations of the shale formations.

Characteristics	Type of Well					
	Dug	Bored	Driven	Drilled		Jetted
				Percussion	Rotary	
Range of practical depths (general order of magnitude)	0–50 feet	0–100 feet	0–50 feet	0–1000 feet	0–1000 feet	0–100 feet
Diameter	3–20 feet	2–30 inches	1¼–2 inches	4–18 inches	4–24 inches	4–12 inches
Type of geologic formation:						
Clay	Yes	Yes	Yes	Yes	Yes	Yes
Silt	Yes	Yes	Yes	Yes	Yes	Yes
Sand	Yes	Yes	Yes	Yes	Yes	Yes
Gravel	Yes	Yes	Fine	Yes	Yes	¼" pea gravel
Cemented gravel	Yes	No	No	Yes	Yes	No
Boulders	Yes	Less than well diameter.	No	(In firm bedding)	(Difficult)	No
Sandstone	Soft	Soft	Thin layers	Yes	Yes	No
Limestone	Soft, fractured	Soft, fractured	No	Yes	Yes	No
Dense igneous rock	No	No	No	Yes	Yes	No

[1] The ranges of values in this table are based upon general conditions which may be exceeded for specific areas

TABLE 3-3 CHARACTERISTICS OF VARIOUS TYPES OF WELLS

A wide variety of *overburden* conditions is present in Ontario. Although much of the area is covered on the surface of the ground with clay or till materials, numerous deposits of sand and gravel are present to provide suitable aquifers in most places for average domestic needs. Areas where there are high-capacity wells for municipal, industrial, or irrigational purposes are less common.

EXTRACTION OF GROUND WATER

Aside from the use of naturally occurring springs, ground water is recovered by means of dug, bored, driven, and drilled wells. Although there are more dug wells in use today than any other type, the number of drilled, driven, and bored wells is increasing as a result of improved methods of well construction and the need for deeper wells which provide a more dependable supply of water. The dug, bored, and driven types of wells are normally the least satisfactory because they are usually the shallowest, are most easily contaminated and are affected by variations in ground-water levels. These types of wells work best in areas where there are sand and gravel in the overburden. Under these conditions, the porosity and permeability of the aquifers allow water to move into the well quickly to replace that which is withdrawn. Dug, bored, and driven wells in areas of tight clay overburden are often without water because the transmissibility of the clay is so low that water will not flow into the well readily; however, a few sandy seams in the clay will sometimes keep the well supplied.

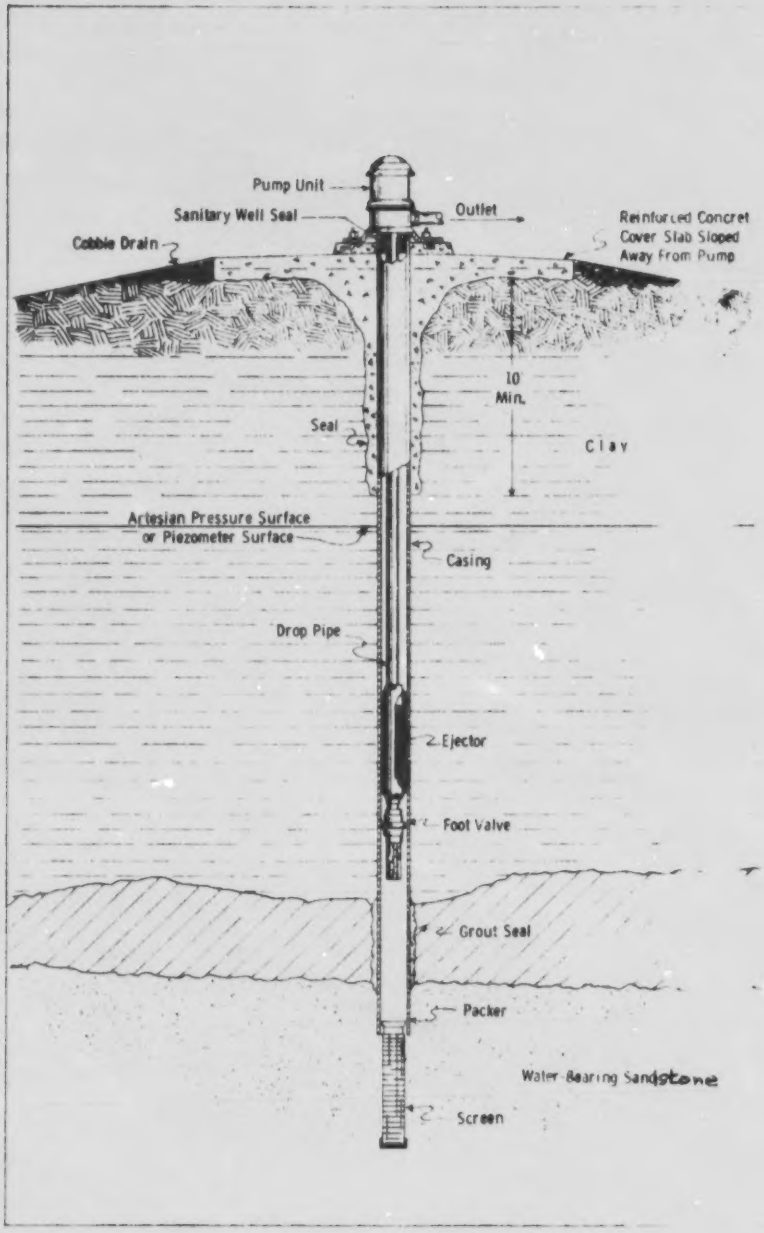


Figure 3-3 DRILLED WELL

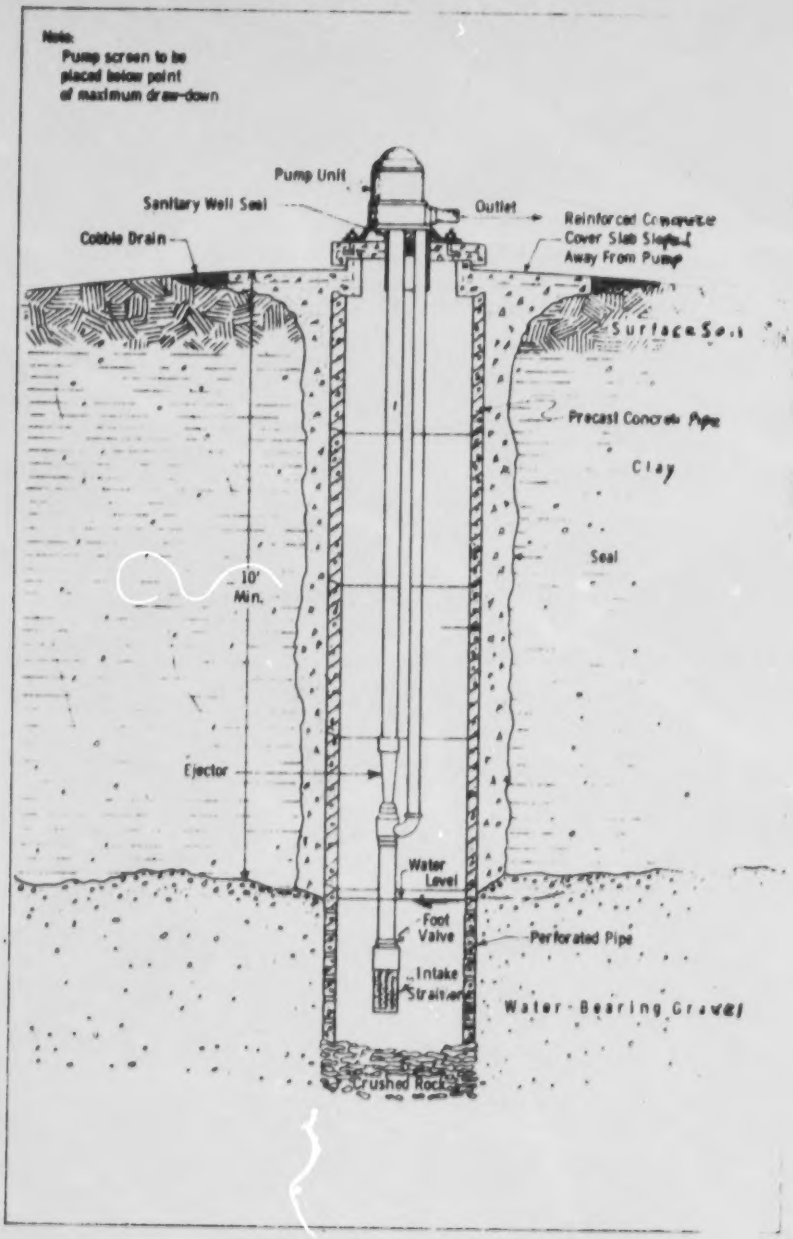


Figure 3-4 Bored Well

Often more reliable sources of water supply are available from drilled wells. Drilled wells usually extend deeper than dug wells into what are known as *artesian aquifers*. This means that the water is coming from an area in the overburden or the bedrock that has more "head". The water in a well drilled into an artesian aquifer rises up above the level where it was first encountered, because of the pressure behind it. If the pressure head is great enough, the well will flow. The flowing well is not an indication that the well is good but that the well head is lower than the pressure head of the water in the aquifer at that point.

Since the only information we are sure of before drilling is the amount of water needed from the well, one or more test holes are usually required. Test holes often become the finished well and are the only sure way to discover (1) *Quantity* of water available, (2) *Chemical quality* of water, and (3) Cost to develop well and produce water from the well.

In *rock wells* several holes may be drilled before intersecting a solution channel or fracture in the bedrock. The test hole that finally intersects this channel or fracture would become the final well.

Drilled wells ending in sand and gravel are sometimes developed with an artificial gravel pack to reduce the velocity of water flow into the well. This helps to keep the water free from sand and silt and the screen free from materials precipitating out of solution. Other wells drilled into sand and gravel are developed naturally with no gravel pack. The rock well requires no screen and, therefore, usually requires less maintenance and rehabilitation. (see figures on page 3-15)

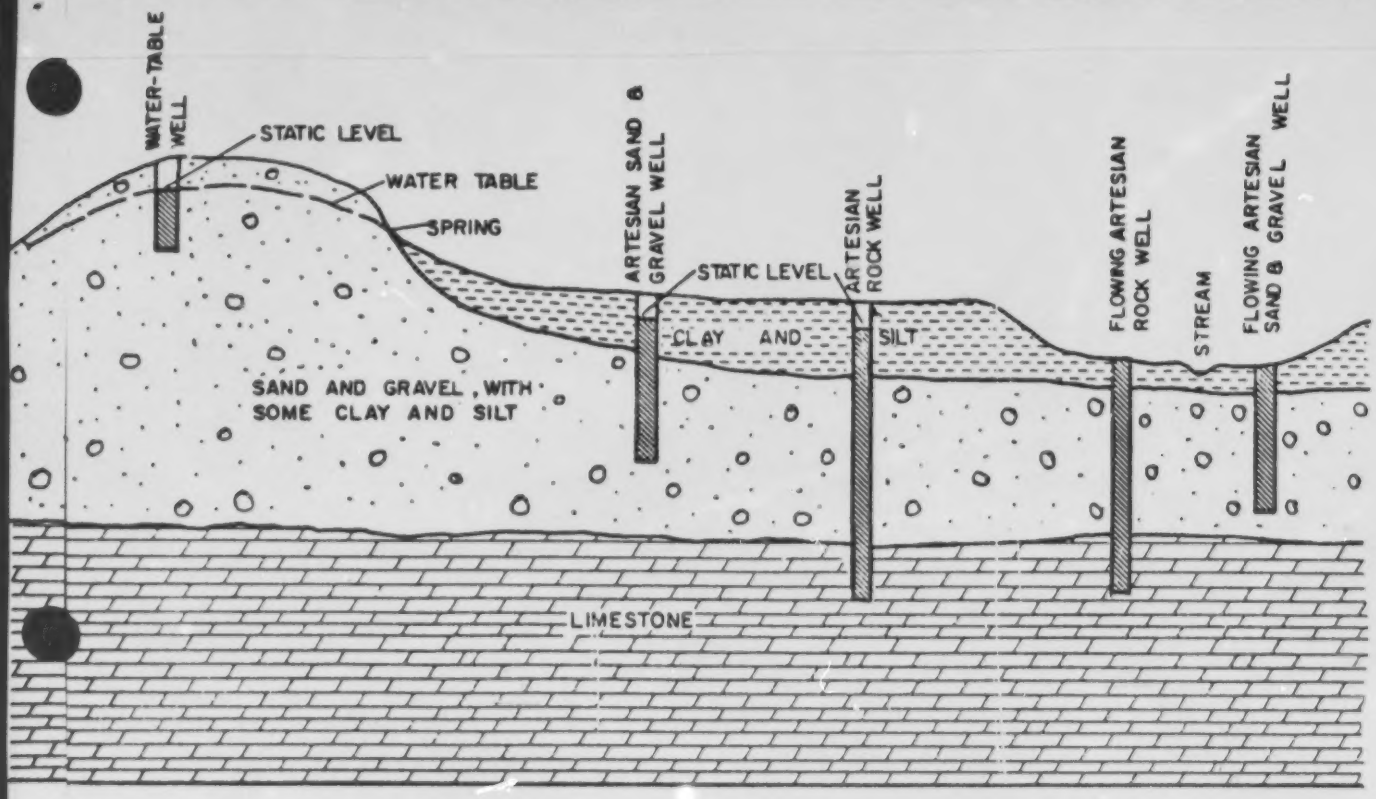


Figure 3-5 ILLUSTRATION OF WELLS COMPLETED IN OVERBURDEN AND BEDROCK FORMATIONS AND UNDER WATER-TABLE, ARTESIAN, AND FLOWING ARTESIAN CONDITIONS.

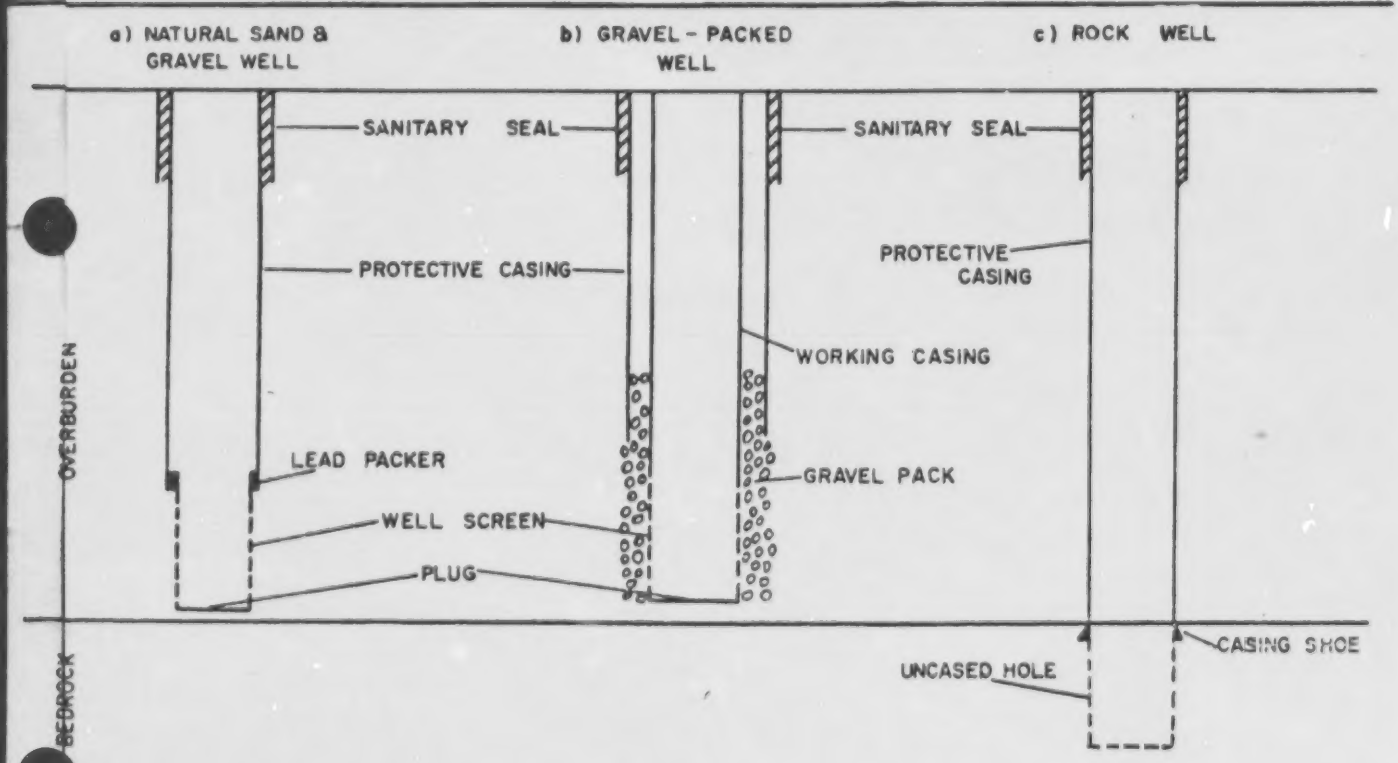


Figure 3-6 COMPONENTS OF SOME TYPICAL TYPES OF DRILLED WELLS.

When water is pumped out of a well, the lowering of water pressure at the well site causes water in the aquifer to flow towards it. It is only natural that there will be a lowering of the water level or water pressure in the vicinity of any pumped well. This lowering forms a *cone of depression* which varies in size according to the rate at which the well is pumped and the permeability of the aquifer. In a *water-table aquifer* (that is, one that is not under pressure), pumping will actually cause a dewatering of the aquifer itself and the cone of depression will spread very slowly. In an *artesian* or *confined aquifer* under pressure (the type into which many of our municipal drilled wells are constructed), the cone of depression is an imaginary pressure surface that spreads out rapidly. The effect of pumping can be observed several hundred or thousand feet away in a few minutes.

When a well is constructed, a pumping test should be run to determine the permeability and storage coefficients of the aquifer. These coefficients indicate how fast the aquifer allows the water to move through it and how much of the water stored in the pores and crevices of the saturated formation is available for use. On the basis of the information obtained from the pumping test, it should be possible to give a fairly accurate rating to the capacity of the well. In such tests, many readings should be taken of water levels in the pumped well and preferably one or more gauge holes, particularly during the early part of the pumping test.

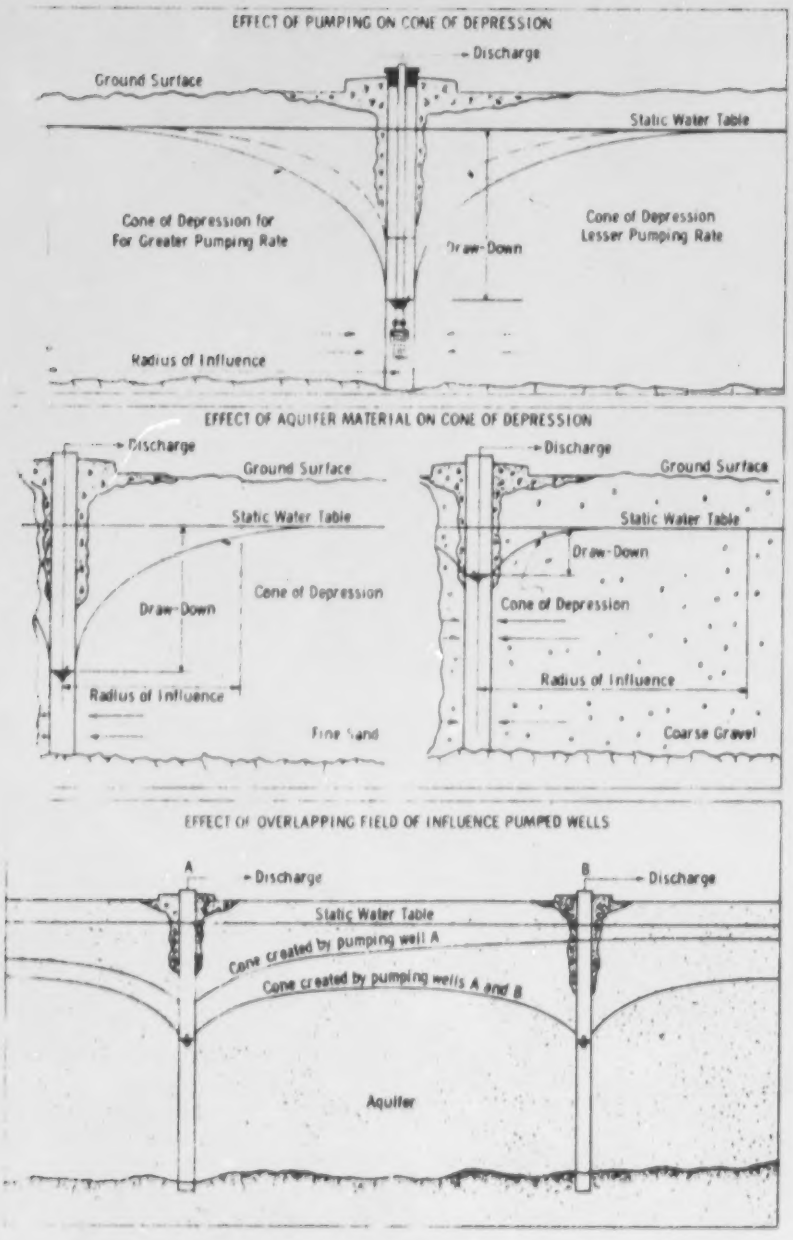


Figure 3-7 PUMPING EFFECTS ON AQUIFERS

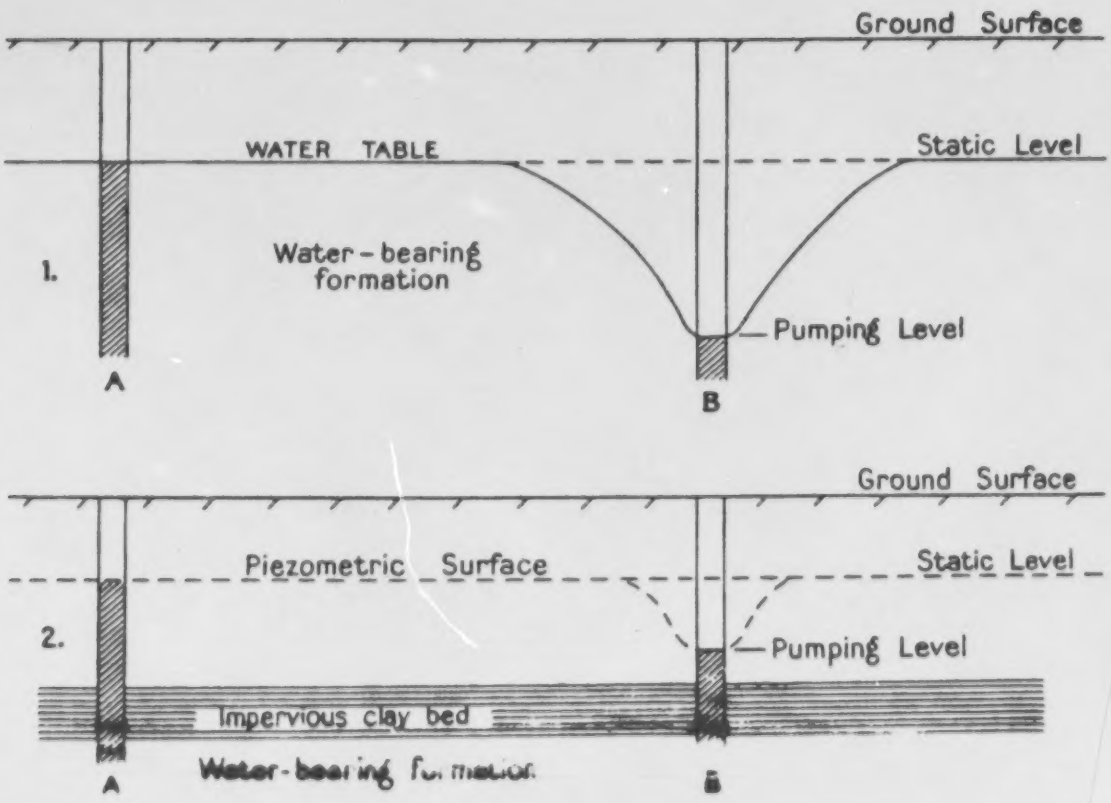


Figure 3-8 Showing the effect of a pumped well on the water levels in adjacent wells under water-table and artesian conditions.

After a well has been put into use, the following observations should be made as regularly as possible:

1. Daily quantity pumped
2. Daily pumping level
3. Daily discharge pressure
4. Weekly static level

Unless these data have been recorded in a careful and orderly manner, it is very difficult to assess the cause of well failures and production decreases.

WELL MAINTENANCE

The operation and maintenance of a well supply are a great responsibility. A pump gets attention because at least some of its working parts are above ground. A well on the other hand, because it is underground and out of sight, is often overlooked until trouble seriously affecting the quantity of water supplied to the pump demands immediate and perhaps costly action. Systematic operation and preventative maintenance, properly worked out for the specific conditions in a locality, can improve overall performance and increase the life of wells.

Probable Causes of Well Failure

The three most common types of well failures are:

1. Failures due to faulty initial well design and construction. Such failures are indicated by difficulty in setting and operating pumping equipment, by partial or total collapse of the well casing, or by the pumping of large quantities of sand.

2. Failures due to pumping the ground water reservoir at rates in excess of the rate of replenishment. Such failures are indicated by a continual lowering of the static level and pumping level in the well, as well as in the aquifer adjacent to it and are accompanied by a decrease in production.

3. Failures due to screens becoming clogged, incrusted or corroded in overburden wells and due to the openings in rock formations becoming plugged or incrusted. Such failures are indicated by increased drawdowns in the well accompanied by a falling off of capacity, while the water level in the adjacent formation remains the same, or by the continuous pumping of fine sand.

Design Failures

Well failures due to faulty design and construction are are in the minority. Such failures are caused mostly by the use of cheap materials, poor construction methods, improperly designed screens as far as strength, diameter and slot size are concerned, poorly designed and placed gravel packs and poorly plugged bottoms. These failures usually give little or no warning.

Difficulties in setting and operating pumping equipment arise when casing diameters are too small to accommodate adequately the pump with the result that the slightest misalignment of the casing causes undue stresses in the pump column. As a general rule, inside diameters of casings should be at least 2 inches larger than the pump.

Collapses of casings, while rare, are possible whenever casing is used that is not strong enough to withstand the vertical and lateral pressures that it will be subjected to under pumping. In actual practice, collapses are prevented by using casing that is usually many times stronger than need be.

Poorly designed screens are the cause of many well failures. Slot sizes, lengths and diameters of screens should be selected with reference to the grain sizes in the aquifer and

the designed capacity of the well. Slot sizes too small for the formation are often specified in order to save development work. Improper selection of screens often results in excessive drawdown in the well because of increased friction losses.

Tremendous pressures are placed on bottom plugs and if the plugs are not carefully placed these pressures gradually loosen them, resulting in leakage of sand into the well.

Generally, failures of the kind just described occur in wells where it was desired to reduce costs to a minimum. This is false economy of the worst kind.

Excessive Pumping Rates

Well failures due to pumping the ground water reservoir at rates in excess of the rate of replenishment are not infrequent and are usually the result of a general lack of knowledge on how to rate the yield of a well.

When a well is pumped, water is taken out of the underground reservoir by the reduction of pressure at the well, thus causing a flow towards the well. If the formation is not pumped excessively, the pumping level will eventually reach a point where replenishment to the aquifer is equal to withdrawal and equilibrium is established. On the other hand, if the formation is pumped excessively, the pumping level will continue to go down as long as the reservoir will supply water and will finally result in failure of the well. In actual cases, what happens is that the pumping level gradually lowers in a well until it is too low for the pump to operate.

Overpumping results in low pumping levels thereby increasing operating costs as well as increasing the rate of clogging of well screens. Such conditions can be discovered only by means of performance records for the well and can be corrected only by regulating the pumping rate to conform with the rate of replenishment. This principle of well operation controls not only the quantity that can be safely pumped from one well but also the quantity of water than can be developed from a group of wells in a given area.

In order to avoid failures due to overpumping, the performance of all wells should be carefully recorded regularly, so that it can be determined when the maximum safe pumping rate has been reached.

Clogging, Corrosion and Incrustation Failures

Well failures due to inlet openings or screens becoming incrusted or corroded are probably in the majority.

Corrosion and incrustation are phenomena which are basically due to chemical changes in the water being pumped due to a reduction of pressure and an increase in the velocity of the water in the aquifer and entering the well. Corrosion of metals is a chemical action set up by the environment to which they are exposed, resulting in deterioration or eating away of the metal. Incrustation, on the other hand, is an accumulation of mineral salts or other extraneous matter in and immediately behind the openings in a well screen.

Corrosion of well screens is not as prevalent as incrustation but it is more harmful, because the metal itself is destroyed. Without considerable experience and some

investigation, it is difficult to recognize the type of corrosion involved, as there are at least six different forms.

The rate of corrosion is dependent on a number of factors, one of them being the rate of movement of water over the surface being corroded. To offset corrosion in wells and pumps, two general methods of approach are common; one is the use of protective coatings and the other the use of highly corrosion-resistant metals. Neither method has proved to be a wholly effective safeguard against corrosion.

Incrustation of well casings, openings, and screens is a deposition of materials in and around all metal parts of wells and pumps. These accumulations are made up largely of the bicarbonates and sulphates of calcium, magnesium, sodium and iron with a variety of lesser minerals. Other agents contributing to incrustation are iron bacteria and slime-forming organisms.

No way has yet been found to prevent or entirely remove these accumulations in and around well screens and pumps. Steps can be taken to retard such accumulations. One way is to design screens so that friction losses in the water passing through the screens and the aquifer are kept as small as possible. Another step is to lower the rate of pumping and increase the period of pumping. This will be effective if drawdown is materially reduced. Some well owners find it more economical to operate a large number of properly spaced wells, with less drawdown, than to try to obtain their requirements from a few wells having excessive drawdowns.

If it is suspected that incrustation is present, periodic cleaning of wells and pumps should be a regular item of maintenance if costly rehabilitation or well replacement is to be avoided.

WELL STIMULATION

In most instances the advice of experts should be consulted before attempting a well improvement program, which must be required if the *static level* is constant but the *pumping level* either drops rapidly, or is beginning to drop lower daily, making water extraction more expensive as well as indicating future failure.

TREATMENT PROCESSES

Figure 3-9 illustrates the most common systems used in Ontario to process ground water. In many instances, Figure 3-9(1), no treatment is required, the water being pumped from the well to the reservoir and then to the distribution system.

Figure 3-9(2) depicts a system where chlorination is required because of adverse bacteriological tests or for distribution system control. When double pumping is used, the chlorine injection point should be to the suction of the high lift pump, or the storage basin. When an agent is used for iron control, chlorine should be fed to protect the distribution system.

Figure 3-9(3) illustrates a system employing aeration and for chlorination to deal with hydrogen sulphide and disinfection and filtration to remove turbidity.

Chlorination and filtration of water supplies are dealt with in detail in later topics.

Figure 3-9 Ground Water Treatment Systems Common in Ontario

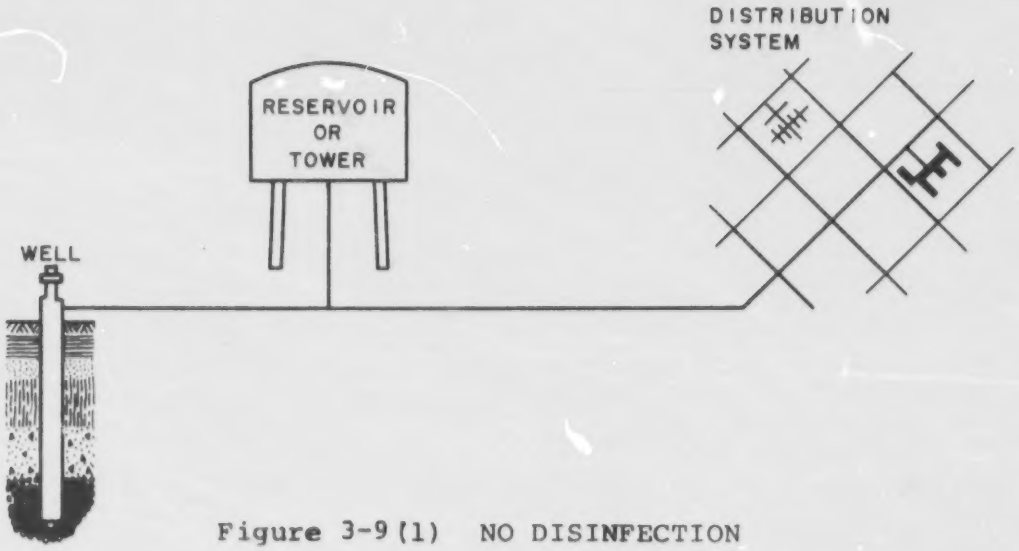


Figure 3-9(1) NO DISINFECTION

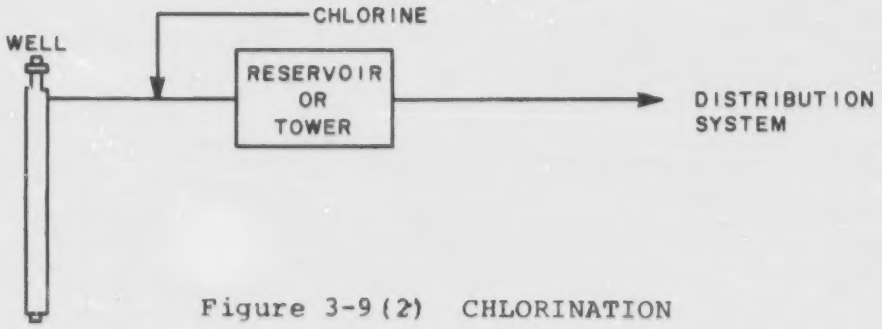


Figure 3-9(2) CHLORINATION

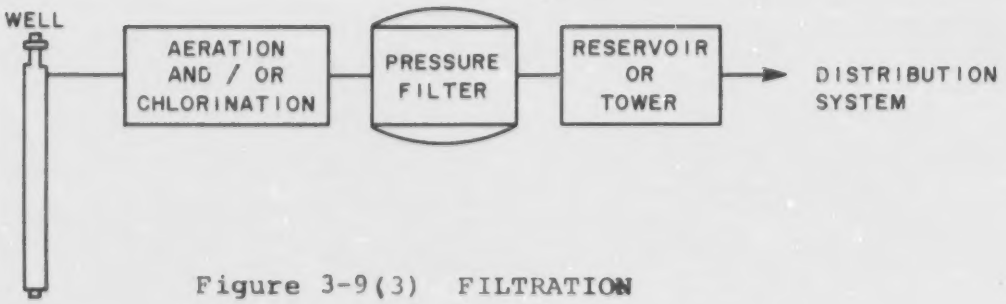


Figure 3-9(3) FILTRATION

SUBJECT:

WATER TREATMENT OPERATION

TOPIC: 4

Coagulation, Flocculation and Sedimentation

OBJECTIVES:

The trainee will be able to:

1. Name the common chemical coagulants.
2. Name and recall the purpose of flocculation aids.
3. Describe, in simple terms, the coagulation and flocculation process,
4. Describe the sedimentation process in:
   - a conventional basin
   - a suspended solids contact clarifier
   - tube settlers.

COAGULATION:FLOCCULATION:SEDIMENTATION

GENERAL

The characteristics of the raw surface water determines the complexity of the treatment process. Topics 1 and 2 discussed the methods which can be used to attain the water quality objectives for bacteriological, physical and chemical characteristics. Figures 4-1 and 4-2 are schematic drawings of the surface water treatment systems in Ontario.

This topic will discuss coagulation, flocculation and sedimentation. Subsequent topics will deal with filtration and chlorination.

Chemicals Used

Coagulants are chemicals that help collect the finely divided suspended particles in the raw water into larger clumps in a short time. These larger particles can then be settled out or removed by a filter.

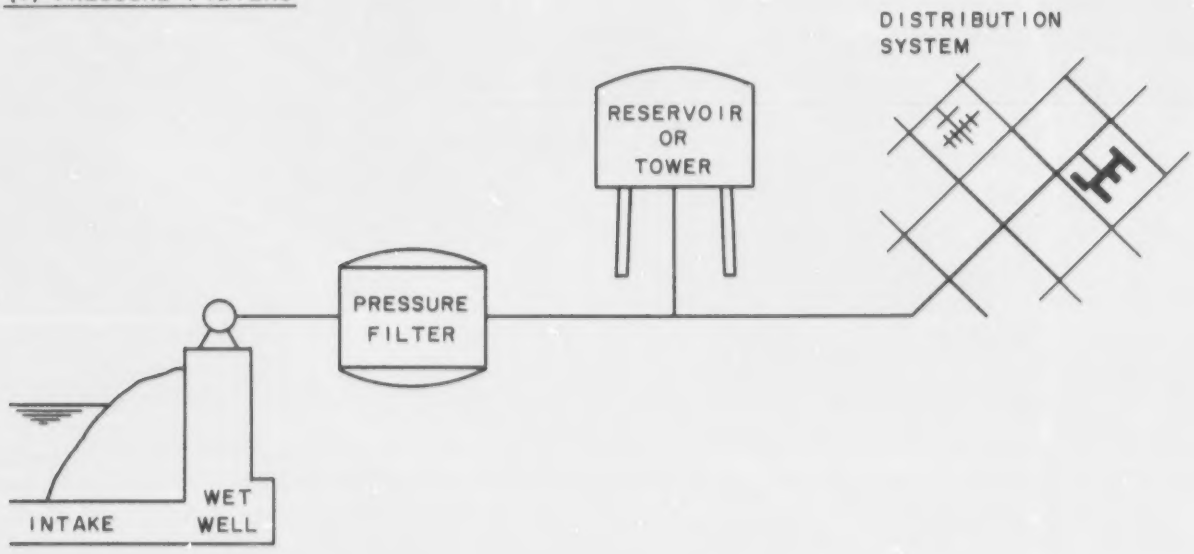
Most of the water treatment plants in Ontario use one of the following chemical coagulants:

NAME		CHEMICAL FORMULA
(1) Aluminum sulphate (alum)		$Al_2(SO_4)_3 14H_2O$
(2) ferrous sulphate	(iron salts)	$FeSO_4$
(3) ferric chloride	(iron salts)	$FeCl_3$
(4) ferric sulphate	(iron salts)	$Fe_2(SO_4)_3$

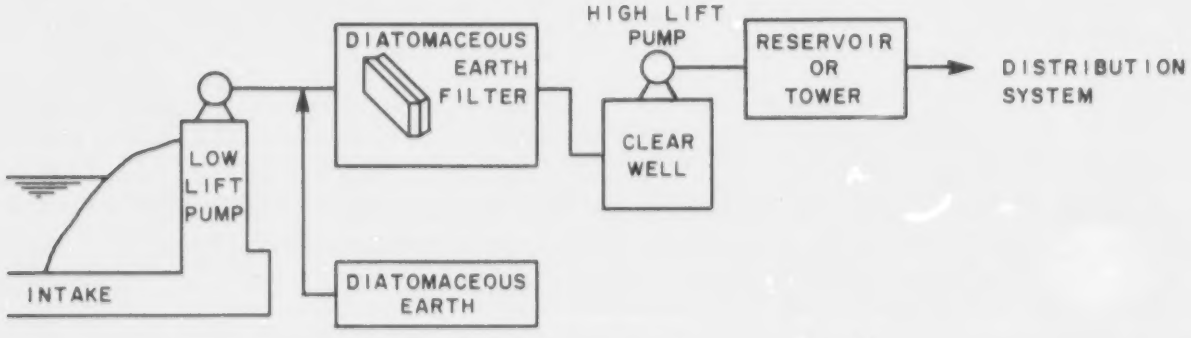
SURFACE WATER TREATMENT SYSTEMS COMMON IN ONTARIO

LOW RAW WATER TURBIDITY

(1) PRESSURE FILTERS



(2) DIATOMACEOUS EARTH FILTRATION



(3) DIRECT FILTRATION

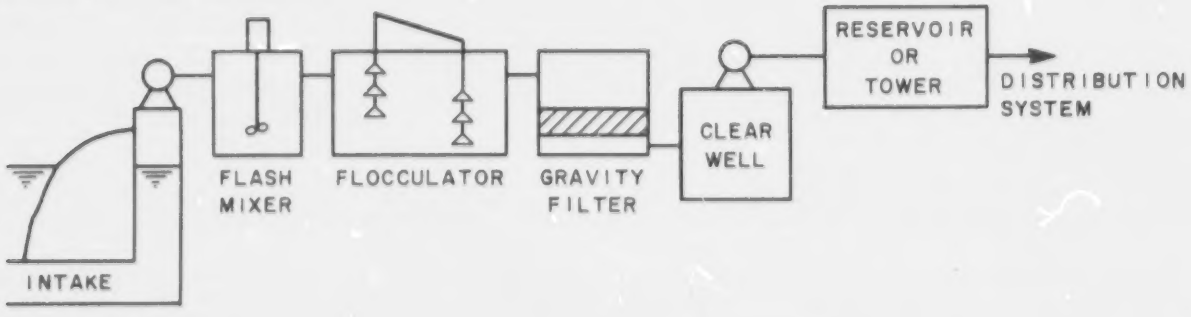
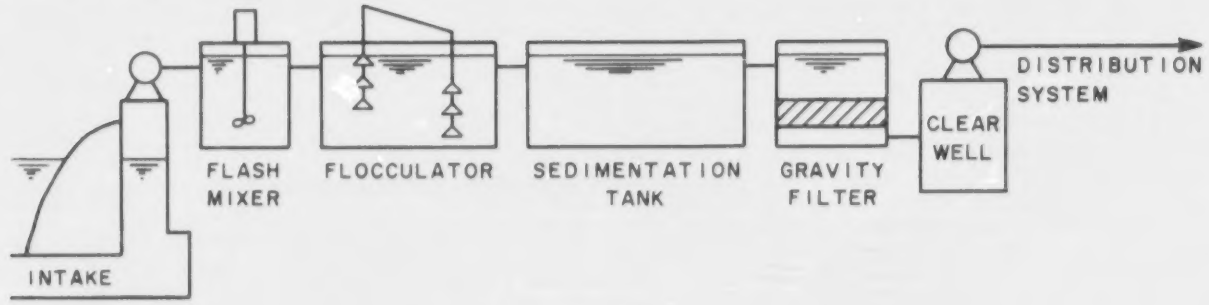


Figure 4-1

SURFACE WATER TREATMENT SYSTEMS COMMON IN ONTARIO

HIGH RAW WATER TURBIDITY

(1) SEDIMENTATION



(2) CLARIFICATION

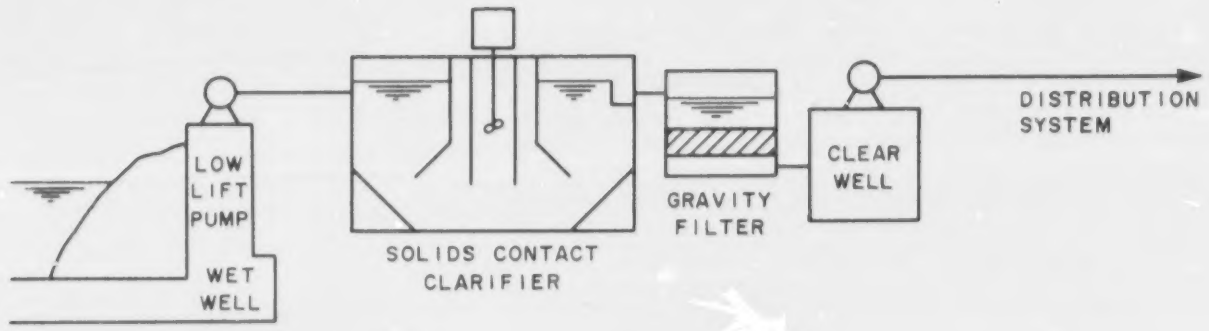


Figure 4-2

Chemical Reactions

Since most water plants use alum as a coagulant, and since the reactions for all chemical coagulants are similar, we will discuss only alum in detail.

When alum is placed in solution, a series of reactions take place within the water itself; this series of reactions constitutes a process broadly described as *hydrolysis*.

Simplified reactions of what takes place are:

$$\underset{\text{(alum)}}{Al_2(SO_4)_3 \cdot 14H_2O} = \underset{\text{(aluminum ion)}}{2\,Al^{+3}} + \underset{\text{(sulphate ion)}}{3SO_4^{-2}} + \underset{\text{(water)}}{14H_2O} \quad \ldots.(1)$$

$$\underset{\text{(water)}}{H_2O} = \underset{\text{(hydrogen ion)}}{H^+} + \underset{\text{(hydroxyl ion)}}{OH^-} \quad \ldots.(2)$$

$$\underset{\text{(aluminum ion)}}{2Al^{+3}} + \underset{\text{(hydroxyl ion)}}{6OH^-} = \underset{\text{Aluminum Hydroxide}}{2Al(OH)_3} \quad \ldots.(3)$$

As the hydroxyl ions are consumed the pH decreases. Recent studies have shown that the chemistry is exceedingly complex. Billions of positively charged structures (O^+) move about in the water and are attracted to billions of negatively charged suspended particles:

$$\underset{\substack{\text{alum complex} \\ \text{(positive charge)}}}{O^+} + \underset{\substack{\text{suspended matter} \\ \text{(negative charge)}}}{.^-} = \underset{\text{(neutralized particle)}}{\odot}$$

The electrical charges are neutralized and the suspended particle is stuck in the alum complex. This all takes place within the first few seconds when the alum is introduced in the water. This is essentially the entire act of coagulation. Because it is very important that the aluminum complex ions are instantly dispersed, high speed mixers are needed. This process is called *flash mixing*.

The following table indicates the advantages of using the proper amount of alum.

Table 4-1 Advantages of Proper Alum Dosage

	Under Dose	Proper Dose	Over Dose
Turbidity Removal	Poor	Good	Fair
Colour Removal	Poor	Good	Fair
Algae Removal	Poor	Good	Fair
Length of Filter Runs	Medium	Long	Short
Residual Aluminum	High	Low	High
$ Value	Wasted	Good	Poor

To learn the correct amount of coagulant to use, a series of tests called *JAR TESTS* can be performed. The procedure for JAR TESTS is described in Topic 10.

Mixers

Three different types of flash mixers are illustrated below.

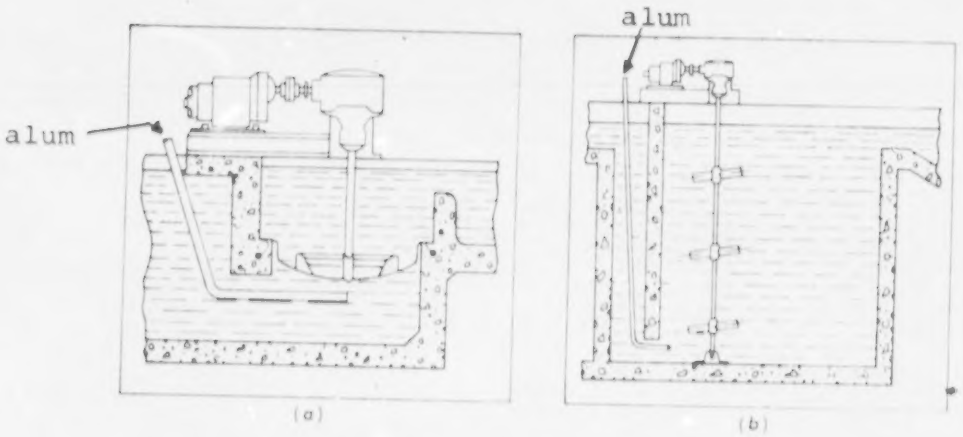


Figure 4-3 Mechanical Mixers
(Retention Time = 20-60 seconds)

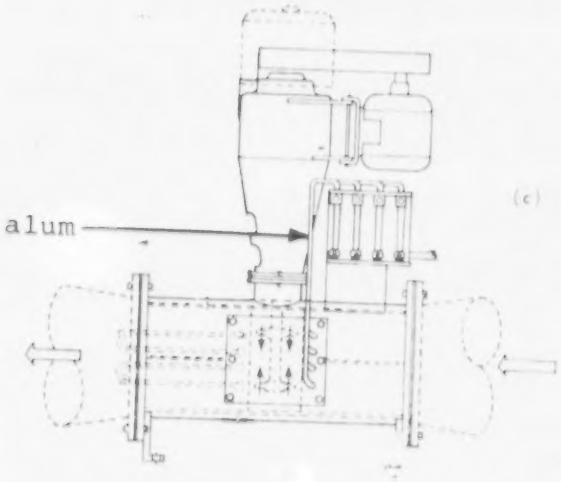
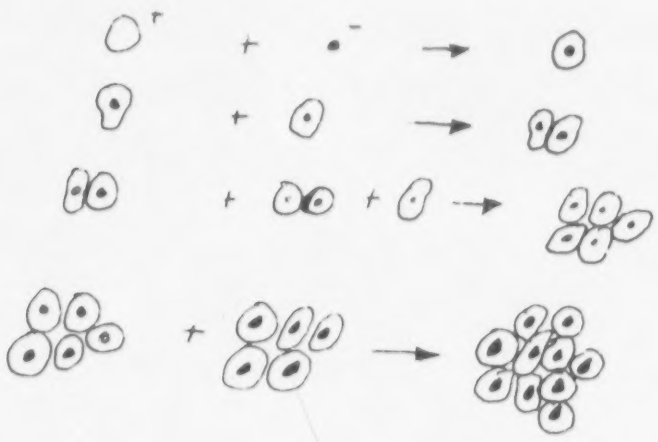


Figure 4-4 In-Line Mixer or Blender
(Retention Time = 1-2 seconds)

After stirring at high speed for about one minute or less the particles are allowed to leave the flash-mix area. The particles then move into a second stage called the *slow mix* in the flocculation stage.

FLOCCULATION

Flocculation is the stage of slow mixing where the small coagulated suspended particles grow through constant collision. The larger particles that are formed are called *floc*. A sketch showing how a floc is formed is shown below.



etc.

NOTE: *A particle collides with a second particle and they "stick" together. In turn, they collide with other particles to form a larger particle. This sticking and growing continues until a certain size is reached.*

The floc becomes larger as the time passes. The final size of the floc depends on the nature of the water and the degree of mixing. Generally, the stirring time varies from not less than 15 minutes to not more than 60 minutes.

As the floc grows, collisions with coarser suspended material and algae take place.

Floc Silt Algae

If algae are present in large numbers in the water, the floc will have a "stringy" appearance.

Although the floc formed contains most of the suspended matter in the water, it is still made up of approximately 96% water. Because of this, it is very fragile and must be treated gently. This means that high speed flocculation must be avoided.

Flocculators

Types of flocculators include the following:

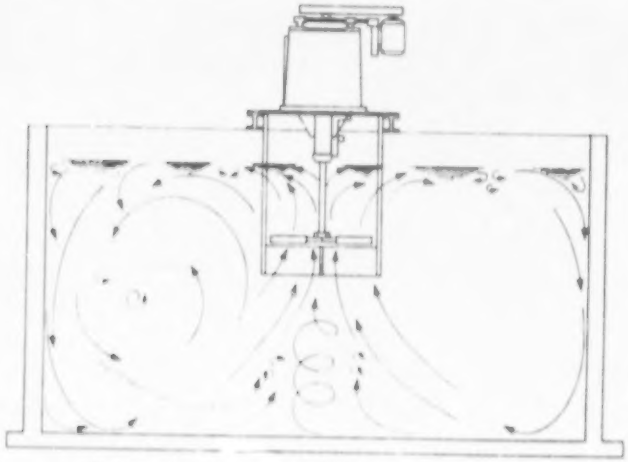
1. axial-flow propeller
2. turbine
3. barrel-roll motion
4. walking beam

(See Figure 4-5 on Page 4-9)

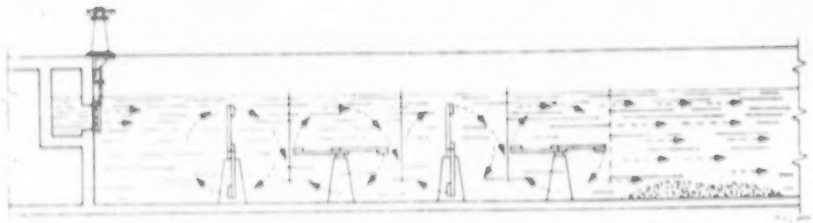
Flocculation Aids

Coagulation and flocculation difficulties will depend on the nature of the water being treated. These difficulties may be due to small and slow-settling flocs during low temperature coagulation, slow settling colour flocs, or fragile flocs that break up under hydraulic forces in settling basins and sand filters. Certain materials, called *flocculation aids*, are added to the water to overcome these difficulties.

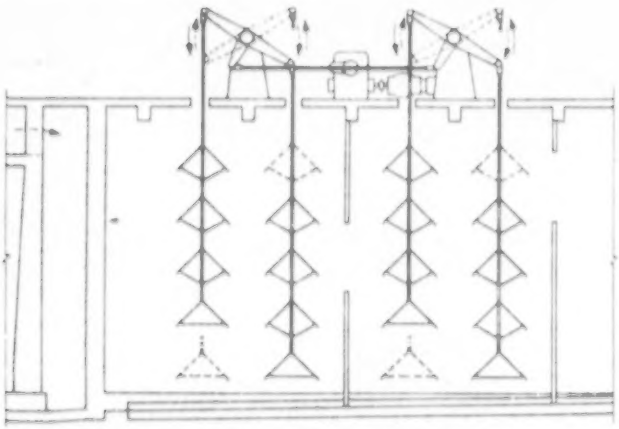
Axial-flow propeller flocculator.



Turbine flocculator. This device is easy to install in existing basins.



Flocculating equipment. A series of paddles placed transversely across the tank width are arranged to impart a barrel-roll motion to the water.



Walking beam flocculator. The up-and-down motion of the paddles provides gentle agitation.

Figure 4-5 Flocculators

Flocculation aids help form a floc that will be tougher and will settle faster. If a floc settles more rapidly, treatment plants may be able to increase their capacity without building extra facilities such as more settling basins and filters.

Flocculation aids include; - adsorbants - weighting agents, activated silica and polyelectrolytes.

1. Adsorbants - Weighting Agents

   Adsorbants - weighting agents such as *Bentonitic clays* are frequently used in treating waters containing *high colour* and *low turbidity*. When using only alum, the floc produced from these highly coloured waters is frequently too light to settle readily. The addition of clay, which is heavier, results in a "weighting action", and a more rapidly settled floc.

2. Activated Silica

   Sodium Silicate in itself is not a flocculation aid. It becomes one when part of its alkalinity is neutralized by an acid and is then considered activated. Activated silica is light blue. The exact nature of the silican compound formed during activation and its behaviour as a flocculant aid is not fully known. Some evidence suggests that during activation, polymers are formed. These polymers, being very long, can physically adsorb onto the floc and form "bridges" between particles. Activated silica should be added to the water either in the flash mixer or in the flocculation section.

3. Polyelectrolytes

Polyelectrolytes consist of long, linear chains of carbon atoms, colloidal in nature and action. Polyelectrolyte molecules possessing negative charges are called *anionic* while those possessing positive charges are called *cationic*. *Non-ionic* polyelectrolytes carry no electrical charges.

Charged polyelectrolytes assume a stretched-out shape in solution while non-ionic polyelectrolytes form a coil.

cationic

anionic

non-ionic

As is the case with activated silica, it is felt that the "bridging" mechanism accounts for the flocculation behaviour of these compounds.

Cationic polyelectrolytes are most frequently used in water treatment because of the positive charge which, like alum, can neutralize the mainly negative charge of the impurities. For many raw waters the amount of alum used can be reduced considerably when a small amount of a cationic polyelectrolyte is added. This is because the cationic polyelectrolyte ties up some of the negatively charged colloid particles, reducing the alum requirements.

Polyelectrolytes are usually added to the flocculation section or at the inlet to the filter.

SEDIMENTATION

Sedimentation is the separation of suspended solids from water by gravity. In treatment plants, sedimentation takes place in sedimentation basins, which may be circular, square, or rectangular. The particular shape of the basins usually depends on the area available and the experience of the engineer designing the plant. The basins should be designed so that the water can enter the basin, pass through, and leave without creating much turbulence. This permits maximum settling of suspended solids.

Most basins have sloped bottoms to aid sludge removal. Depths usually range from 8 to 16 feet. The time required for a unit volume of water to flow through the sedimentation basin *(retention time)* is usually a minimum of 2-2½ hours.

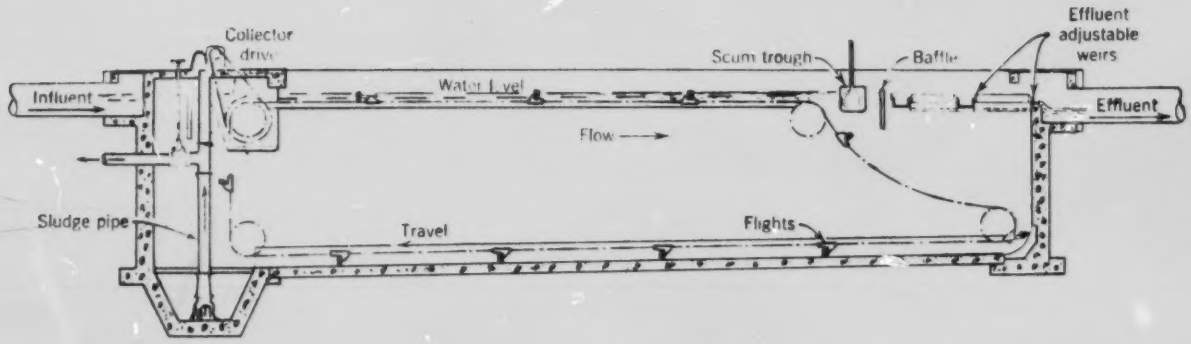


Figure 4-6 Rectangular Basin - Mechanically Cleaned

Tube Settlers

A recent development in sedimentation is installation of small, parallel tubes, called *tube settlers*, near the surface of the water in the settling basin. Tube settlers can reduce the total volume requirements of the sedimentation systems or be used with existing systems to allow an increase in the volume of water passing through. Sedimentation takes place more rapidly since the floc has only a short distance to settle.

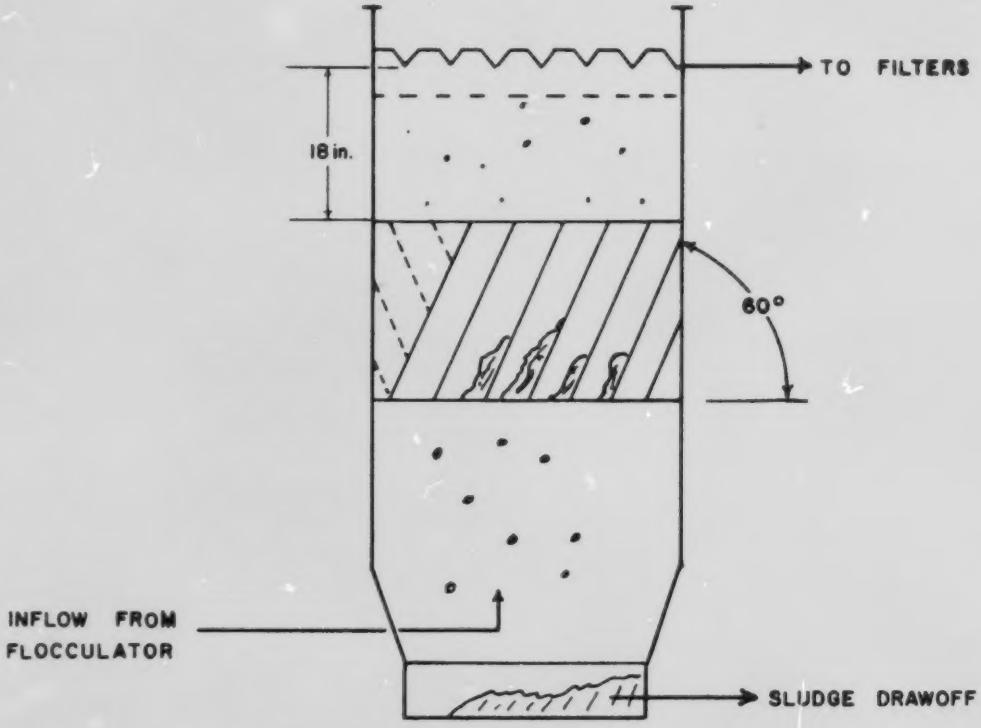


Figure 4-7 Steeply Inclined Tube Settlers

(Floc settles on side of tube, then slides down to the bottom where it is removed continuously.)

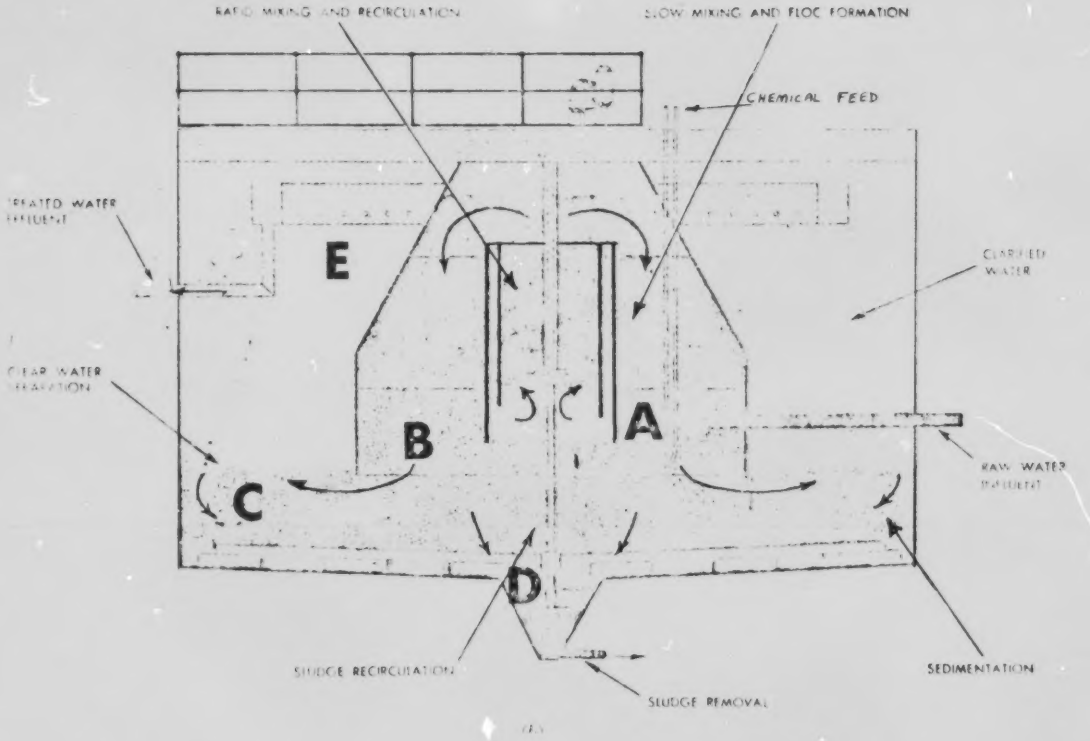


Figure 4-8 Graver "Reactivator" Treatment Plant

SUSPENDED SOLIDS CONTACT CLARIFIER

Suspended Solids Contact Clarifiers combine mixing, flocculation, clarification and sludge removal in a single unit. Many commercial types are available.

Graver "Reactivator"

After coagulation has taken place (A) the solids are mixed slowly (B) and rise into the floc blanket area (C). There, the solids are suspended between the downward force of gravity and the upward force of the rising water. Due to the constant collisions of the floc in this area, the flocs gather together until they are heavy enough to sink to the bottom of the clarifier. They are then drawn-off as sludge (D) at fixed intervals so that a constant volume of sludge remains at all times in the bottom of the clarifier.

During this time, the now clarified water rises to the overflow, and passes to the filters (E).

Suspended Solids Contact Clarifiers require less space than flocculation and sedimentation basins. They may also cost less, but they are usually not as flexible in their operation.

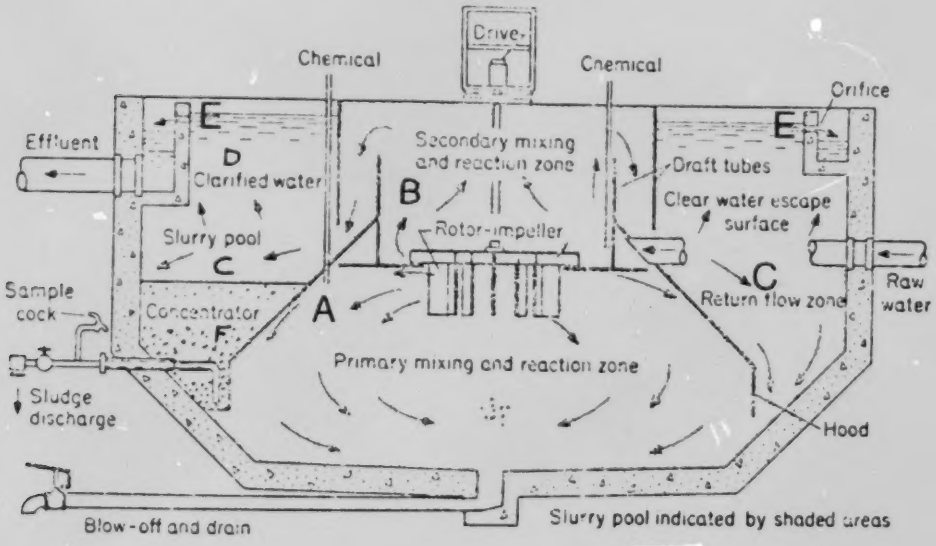


Figure 4-9 Infilco "Accelator" Treatment Plant (Solids Contact Unit)

Infilco "Accelator"

Coagulation and the first stages of flocculation take place in the primary mixing and reaction zone (A). The rotor-impeller drive pulls and pushes the floc into the secondary mixing zone (B) where the flocculation process continues. The floc rises over the up-draft tube and under the down-draft tube, and spills into the slurry pool (C). There, the floc behaves as if it had just entered a sedimentation basin. The force of gravity, as well as the force from the rotor-impeller drags the floc down. The clear water rises up into the upper regions of the clarifier (D) and spills into the overflow weirs (E). The floc, now part of the slurry pool,

is dragged back into the primary mixing zone (A) and the cycle continues. Some of the heavier floc particles settle into the concentrator(s) (F). The floc (now called sludge) is periodically drawn off from the concentrator. There is very little settling at the bottom of the primary mixing zone (A), due to the high mixing rate of the rotor-impeller.

SUBJECT: WATER TREATMENT OPERATIONS

TOPIC: 5 Water Filtration

OBJECTIVES:

The trainee will be able to:

1. Recall the purpose of filtration;
2. Describe the filtration process;
3. Define and describe the three operating items to be checked for optimum capacity and maximum efficiency;
4. Recall what is meant by:
   a) filtration rates
   b) backwashing
   c) washing with air
   d) water scour;
5. Define and describe the operating problems of a filter;
6. Recall:
   a) how to do a "probe" check
   b) how to check the "actual loss of head" across a filter
   c) how to check the "actual rate of flow" through a filter;
7. Recall the operation of:
   a) a pressure filter
   b) a diatomaceous earth filter.

WATER FILTRATION

PURPOSE OF FILTRATION

The primary purpose of filtration is to protect public health. In the earlier days of filtration, this was the only purpose in treating the water. Today, however, this is no longer true. The tremendous growth in cities and industry made it necessary to remove any objectionable odours, tastes and colour as well as providing an absolutely clear finished product.

GENERAL CONSIDERATIONS

Most of the potable and industrial water supplies in Ontario come from surface water-lakes, rivers and streams. The pollution in surface waters requires adequate treatment to make them safe to use. A water purification plant not only produces a safe water but also provides water which has no objectionable taste, odour or colour.

This may be accomplished by:

1. treating the "raw" water entering the plant with various chemicals,
2. mechanically agitating it for proper mixing and coagulation of the chemicals for flocculation and
3. allowing enough retention time in the plant to settle out most of the suspended matter.

The next and most important phase through which it passes is - *FILTRATION.*

Filtration is the process of removing turbidity (suspended particulate matter) from water by passing it through some porous filter media such as sand, anthrafilt or a combination of both.

FILTRATION PROCESS

Laboratory test results and observation have shown that the filtration process removes almost all kinds of turbidity from the water supply. This is accomplished by **Mechanical Straining, Impingement, Electrolytic Action and Chemical Reactions.**

1. Mechanical Straining
   The largest particles remain on top of the filter because their size will not allow them to pass through the small space between the individual grains of media.
2. Impingement
   Do you remember as a small boy sailing match sticks tended to float to the side of the stream and stick to the curbing? Did you ever wonder why it is that when you drive your car through mud in the pouring rain, that the mud splashed onto your car instead of washing off with the rain? The action taking place in either case is the same when turbid water passed down through the sand grains in a filter. A natural attraction causes the particle to move to the surface of the media and stick to it.
3. Electrolytic
   Both sand and anthracite grains carry an electrical charge as do particles of turbidity which are suspended in the water. These electrical charges change the physical and chemical makeup of the constituents, affecting their ability to filter.
4. Chemical Reactions
   There are many organisms in the top layer of the filter media. These organisms will promote chemical reactions with incoming turbidity and other organisms, affecting the filtering action.

THE "SLOW" SAND FILTER

Filtration, as we know it today, began in about 1830 when the first of the so-called "slow" sand filters was constructed and put into use in London, England. These units operated at rates of flow of from 2 to 10 MGD per acre. (equivalent to 1/10 g.per sq. ft.). The "slow" sand filter is fast disappearing mainly because of the high cost of labour required to operate this type of unit, and the amount of the land required.

The "slow" sand filter consisted of an underdrain system with a gravel bed over it. On top of this was spread the filter sand. The water flowed in on top of the sand and filtered down through it, depositing the turbidity in the upper layers of the sand. During its passage through the sand layer the bacteria already present in the filter attacked and in most cases, destroyed any harmful bacteria present. The water was purified by this method rather than by chlorination. In fact this was the only method of disinfection which was practiced at that time. Once the rate of flow became too slow for any further operation, the water was shut off, the unit drained, and the top layer of sand removed. The cost of removing the sand by hand and replacing it regularly was considerable.

THE "RAPID" SAND FILTER

The "slow" sand filter evolved into the "rapid" sand filter which is in use today. The "rapid" sand filter can either be of the gravity or the pressure type. In either case, the water passes downward through the bed of sand at rates of flow from 2 to 8 gpm per sq. ft.

Because of a much higher rate of flow, the water is usually pretreated by coagulation and settling to remove the greatest part of the suspended matter before the actual filtration process. At this higher rate relatively little purification took place by the bacterial method and in its place chlorination was practiced for disinfection. Unlike the "slow" sand filter, the "rapid" sand filter can be cleaned of the accumulated turbidity by reversing the direction of the flow of the water. This process is called *backwashing*. In backwashing, the flow of water through the sand expands and scours the bed and carries away, in the water stream to the sewer, the accumulated solids.

The media used in the "rapid" filter today, include *sand, crushed anthracite coal* and in some cases, a combination called *mixed media*.

CONSTRUCTION OF A SAND OR ANTHRACITE FILTER

A gravity filter is essentially a concrete box. Its length, width and depth are determined to suit the configuration of the building, and the rate of flow which is desired. The depth of the box is determined by the amount of *head* or pressure required and also by the type of underdrain which is used.

The principal parts which make up a gravity filter are shown in(Fig. 5-1) and include the *underdrain system*, the *gravel subfill*, the *filter media*, the *surface washer* and the *wash troughs*.

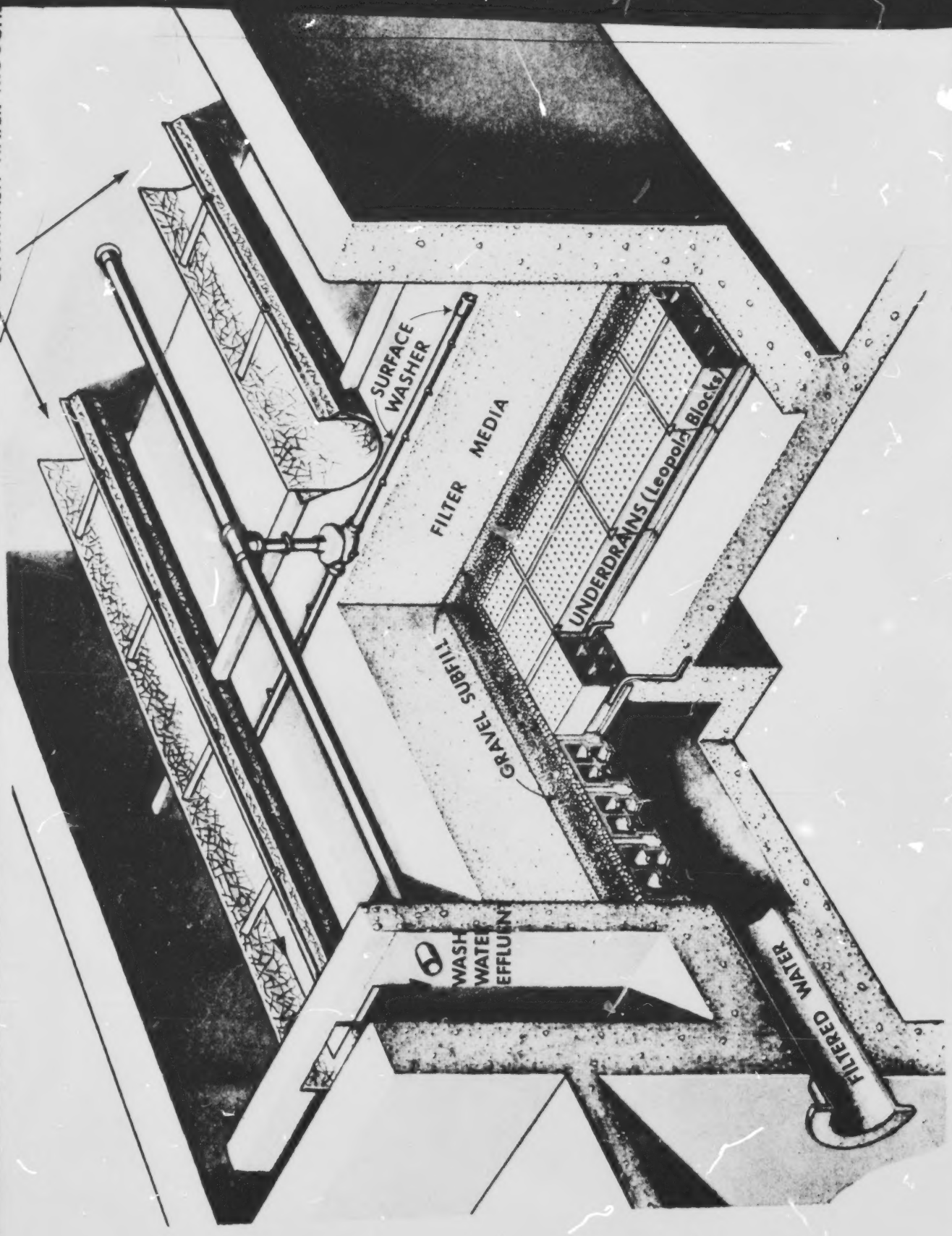


FIG. 5-1 CUTAWAY VIEW OF TYPICAL RAPID SAND FILTER

1. Underdrain System

The underdrain system collects the filtered water that passes through the media. The most common type of underdrain is the vitrified clay "LEOPOLD" drain tile. Holes are on the upper side of the drain tile and are properly sized to handle the water flows required for adequate backwash distribution at all times. The backwash flow rate of the average filter is 12 to 15 gallons per sq. ft. per minute and the operating rate only about 4 gals. per sq. ft. per minute. Since the only head available during the filtration process is the depth of water in the filter, the holes are normally sized to handle the filter flow. Adequate distribution is ensured at the higher flows encountered in backwash pump, or washwater tank.

2. Gravel Subfill

The subfill performs two primary functions:
(1) It keeps the bed of the filter media, which is extremely fine, from passing out through the holes in the underdrain system.
(2) It distributes evenly the flow of water coming from each of the holes in the underdrain system. Thus an even flow passes either up or down through the bed of filter media. (The depth of gravel required in any design of filters is directly related to the distance between the holes in the underdrain system.)

Differenct layers, or size, of gravel make up the required depth. Progressively finer grades of gravel are spread on top of the coarse gravel;

the minimum depth of a layer is 2" and the final layer of gravel, or "torpedo sand" as it is sometimes called, will support the actual filter media.

3. Filter Media

The actual filter media is on top of the bed of gravel and is usually up to 30" deep. The original media used was sand. Later, crushed anthracite coal was used. Today, with the advent of multi-media systems, garnet and other types of sand are used. These materials incorporate in the grain structure such things as carbon which greatly reduce their weight.

"Anthrafilt", a brand name, is actually anthracite hard coal which has been crushed (screened) for size and graded to have a uniform density. Crushed anthracite coal has a lower Specific Gravity (1.75) than sand (2.65); consequently, a lower velocity is required when backwashing the filter.

Crushed anthracite coal is lighter in weight (55lbs. per cu. ft.) than sand (100 lbs. per cu. ft.); therefore, in order to benefit from both of these media, they are generally used together. They can be readily backwashed together and should always remain separated due to the difference in their backwash characteristics. The coarse anthracite on top gives the filter a larger capacity for turbidity removal. The combination of the two provides a media that will give longer filter runs with a resulting better quality of water.

4. Surface Washer

The surface wash equipment is positioned directly above the top surface of the filter media. It may be (1) a fixed grid of pipes with nozzles, (2) a rotat-

ing tubular arm with small jets all along the trailing side or (3) a grid which introduces compressed air into the filter media as an air wash. Any of the three methods can be used to remove any and all suspended matter from the filter media.

5. Wash Water Troughs

The wash water troughs are located above the surface wash equipment. They are installed high enough above the bed to provide a free space between the underside of the trough and the top of the bed equal to half the bed depth. This is the backwash space normally provided for the filter media to expand into for adequate cleaning. The depth of the wash troughs varies with the amount they can hold so the distance from the top of the wash trough to the top of the bed will range widely.

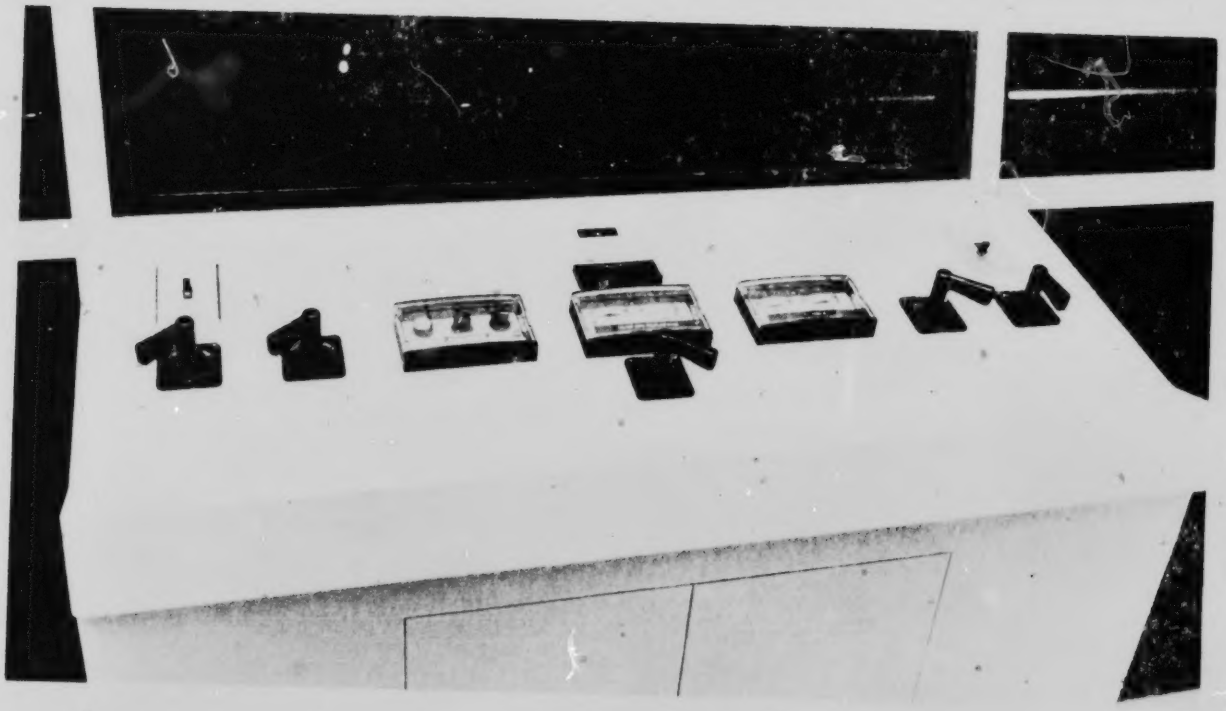
6. Other necessary accessories include the influent, effluent and wash water valves, and a valve to control the flow of water to the surface wash equipment. All of these valves are controlled from a console, located in front of and facing the filter. Built into the control console are gauges showing loss of head, rate of flow through the filter, and backwash rate of flow.

In some older plants, especially the smaller ones, individual hand valves are still in use. The large, newer plants feed data such as filter flow rate and loss of head into master control consoles which automate the valve operations required to backwash a filter and return it to service.

FILTER INSTRUMENTATION

To operate a filter at its full capacity and highest efficiency, the status of the filter is checked

Filter Control Gallery



Filter Control Console

Fig 5.2

continuously and the *turbidity* (before and after filtration); *loss of head*, and the *rate of flow*, are recorded.

1. Turbidity

   The prime function of a filter is to protect the public health by removing disease producing organisms from the water. Most of these organisms are bound up in the coagulated floc particles entering the filter. The turbidity remaining in the filter effluent is the best indicator of filter performance. Turbidities can be measured in the laboratory by such instruments as the Hellige or Hach turbidimeter, and can be monitored on the filters with indicating and /or recording type instruments such as those produced by Keen and by Hach manufacturers.

2. Loss of Head

   A filter was earlier described as a concrete box with an underdrain gravel subfill and filter medium; the box, of course, is filled with water. In most filters, the distance from the surface of the water to the centre of the underdrain system is approximately 10 feet. This is the total head or pressure available to push water through the filter. When the filter has just been backwashed, it is in its cleanest state and offers the least resistance to flow through it. This is called the smallest or lowest loss of head of the filter and is usually less than 2 feet. The maximum head available during the filter run is the difference between the total depth and the initial loss, leaving an available head in most filters of about 8 feet (10 feet - 2 feet).

When in operation, the filter removes the turbidity from the water. As the turbidity accumulates in the bed, the resistance to the flow of water increases; in other words, the loss of available head through the filter increases. Therefore, the reading of the loss-of-head gauge is an indication of the "cleanliness" or the"dirtiness" of the filter. The loss-of-head gauge indicates when the filter needs backwashing. A simple loss-of-head gauge can be constructed by connecting a clear piece of plastic tubing to the underdrain header and running the tubing up to the side of the filter box so that the open end of the tubing is above the surface of the water in the filter. Mark the level of the surface water in the filter on the wall next to the tubing. Then, at any time, the distance from this point down to the liquid level in the tube can be measured -- this distance (in feet) is the head loss. Most modern loss-of-head instruments operate on this principle and simply transmit the measurement (or distance) to the instrument located on the control panel.

3. Rate of Flow

There is a change in pressure loss through a gravity filter during the period of the run. If there is a variation in the pressure loss across the filter and the total amount of head available in the filter is constant, the rate of flow through the filter will vary with the pressure. This does not lead to the best developed to overcome this changing pressure and make the filter operate at a constant rate of flow. The rate of flow controller consists of an effluent valve and a measuring device, in most cases a venturi tube, which allows the water to flow from the filter at a constant but adjustable rate, independent of the change of pressure loss or loss of head within the filter proper.

The venturi tube is designed to measure two pressures and the difference in the two pressures will vary with the rate of flow. These two pressures are applied to the controlling diaphragm of a valve so that as the rate of flow through the tube decreases, the valve opens. This way a constant flow is maintained.

FILTER OPERATION

Pre-Treatment

The most important thing to remember about the water arriving at the filter (s) is to condition and pretreat it thoroughly before it ever gets there. Without this pretreatment, (or if the pretreatment is insufficient), the operating efficiency of the filter(s) is going to be drastically reduced. Filter runs will be cut short, resulting in a considerable increase in backwashing and the amount of wash water used. Consequently, plant output will be reduced because filters have to be washed with filtered water. The filter beds will become overloaded with algae and particulate matter, and mud balls will very likely develop.

The type of conditioning applied to the raw water depends on the quality of the raw water entering the plant. The demand on water treatment plants, however, is continually increasing. If a given chemical treatment produces a good floc, coagulates well, and results in a water passing over the filters with, for example, turbidity of one (1) unit, at a flow rate of 25 MGD, an increase in flow rate to 40 MGD may not produce the same quality water over the filters even if the chemical dosage is increased in proportion to the increase in flow. This is because increasing the flow rate by 60% will allow less time for the floc to settle out. This results in a greater "carry-over" to the filters, causing shorter filter runs.

Filtration Rates

Until a few years ago, the normal design filter rate for a rapid sand filter producing potable water, was two gallons per minute per sq. ft. of filter bed area. Since then investigations of filter aids have been carried out, using dual and multi media filters As a result, operating filter rates can be notably increased. It is common today to find filters operating at rates of 5 gal. per minute per sq. ft. of filter bed area. These newly designed filters use a media in which the particle size is greatest at the top. By using various types of filter media, the particle size gets progressively finer, down through the bed to the bottom. Since the voids (or spaces) between the particles will be larger where the particle size is greatest, the voids in the upper portion of the bed are at their maximum. These provide a great storage area for turbidity particles. As the water proceeds through the bed, the size of these voids becomes progressively smaller due to the accumulation of turbidity particles. At the same time, the storage for the turbidity is becoming less, but the degree of filtration is becoming better.

It is common today to have up to five different layers of material in a filter bed. In other types of media, two layers are used, generally sand and crushed anthracite: two-layer filters are commonly known as dual media filters. Choosing the type of process to be used can only be done after a thorough study of the treatment process and raw water conditions.

It is not always possible to increase the rate through any particular filter. Filters are normally designed for specific rates of flow, and such things as the inlet flumes, the underdrain system, rate of flow controllers, and the discharge piping are all sized for this flow.

For example, to double the rate of flow, the total head available in the filter may be sufficient to maintain this increase in flow rate. In many plants, it is possible to have two different rates of flow at different times of the year. This is particularly true when treating waters that are difficult to coagulate. The rate of flow through the plant may be reduced during the winter months, in order to compensate for the poor quality of water being fed to the filters.

The conventional rapid sand filter uses one grade of sand (0.45-0.55 mm and a S.G. of 2.65) approximately 30 inches thick underlaid by graded layers of gravel as supporting media. Normally under these conditions, the actual entrapment of suspended matter is restricted to the top two inches of the sand bed. The remaining 28 inches of sand act as insurance against a serious turbidity *breakthrough*, which means the turbidity on the filter has increased to the point where it is being carried through by the water being filtered.

The storing capacity for suspended matter in the conventional rapid sand filter is considerably less than in a dual-media filter where the top 18 inches of the sand bed have been replaced with a coarser and lighter media, such as a graded crushed anthracite (0.8-1.2 mm and a S.G. 1.75). Under ideal conditions, the entire 18 inch depth of anthracite plus 1-2 inches of sand, is available for the storage of suspended matter. This means that the head loss, instead of being concentrated in the top 2 inches in the conventional sand bed, is distributed through a depth of 18-20 inches in the dual-media bed. This makes it possible to use higher filter rates for longer filter runs. Under these conditions, however, it is common practice to apply a small dosage of polyelectrolyte to the water just before it reaches the filter. This is in addition to the alum, which is applied as a part of the pre-treatment process.

Since the dual-media bed has a good deal of storage capacity in the anthracite layer, it should be possible to use the anthracite layer instead of a sedimentation or settling tank. This is called *Direct Filtration.* The turbidity in the raw water should be relatively low (say less than 15 units on the average and maximum turbidity levels of 50 units and the algae concentrations are also desired to be low.

Backwashing (see Fig. 5-3, 5-4)

Backwashing a filter is the exact opposite to filtration. When backwashing, the water rises up through the filter rather than passing down through it. The backwashing process removes the accumulated turbidity from the filter. Municipal filtration plants always utilize treated water for backwashing. The water is delivered to the filter either from an elevated tower or via a backwash pump (from the clearwell). Either method provides the necessary pressure and volume for carrying out the back wash process.

A normal rate of flow during the backwash cycle for conventional filters is 15 gal. per minute per sq. ft. of filter bed area. These figures will vary depending on the temperature of the water used to backwash. As the temperature increases, the backwash rate is increased to give the same amount of expansion to the filter bed. The backwash water enters through the underdrain head by the holes of the underdrain system. Rising up through the gravel bed, it enters the filter media. The gravel bed further distributes the water uniformly throughout the entire filter. It is extremely important to note *that in the operation of any filter, all valves be opened or closed slowly.* As the backwash valve is opened, the amount of water rising up through the filter media gradually increases and as more and more water is forced up through the sand bed, the pressure on the underside of the individual grains of filter media becomes greater.

This pressure eventually overcomes the weight of the particle of filter media and the point at which this occurs is known as *the point of fluidity*. Once the flow reaches this point, the particle will rise and the filter bed will start expanding. The normal expansion of the filter bed is 30 to 50 per cent during the backwash period. Backwash space must be provided in the filter to permit this expansion during the washing period. This is why the wash trough must be at a fixed height above the filter bed. The particles of media roll around in the bed, continuously rising and falling. In the process, they rub against each other. The combined action of the water moving past the particle of media and the scrubbing action of the particles rubbing against each other removes the accumulated turbidity from the filter media grains.

It was found from experience that this does not always remove all of the turbidity from the filter media, and that over the years, turbidity will accumulate on the media grains, limiting their effectiveness as a filter media.

To overcome the turbidity build-up on the filter grains, various types of surface wash systems are used. These systems consist of water jets aimed down on the grains of filter media and physically aid in removing the layer of accumulated turbidity. The most common unit in service today is the Palmer filter bed agitator. This unit is installed directly above the bed and is a self-propelled revolving agitator incorporating high velocity nozzles or jets. The jets are inclined to discharge at an angle down into the filter bed. The jet of water helps clean the filter media and also propels the arm, causing the entire assembly to rotate. It is most important to use the maximum water pressure designed for these units. Without enough pressure, they are ineffective.

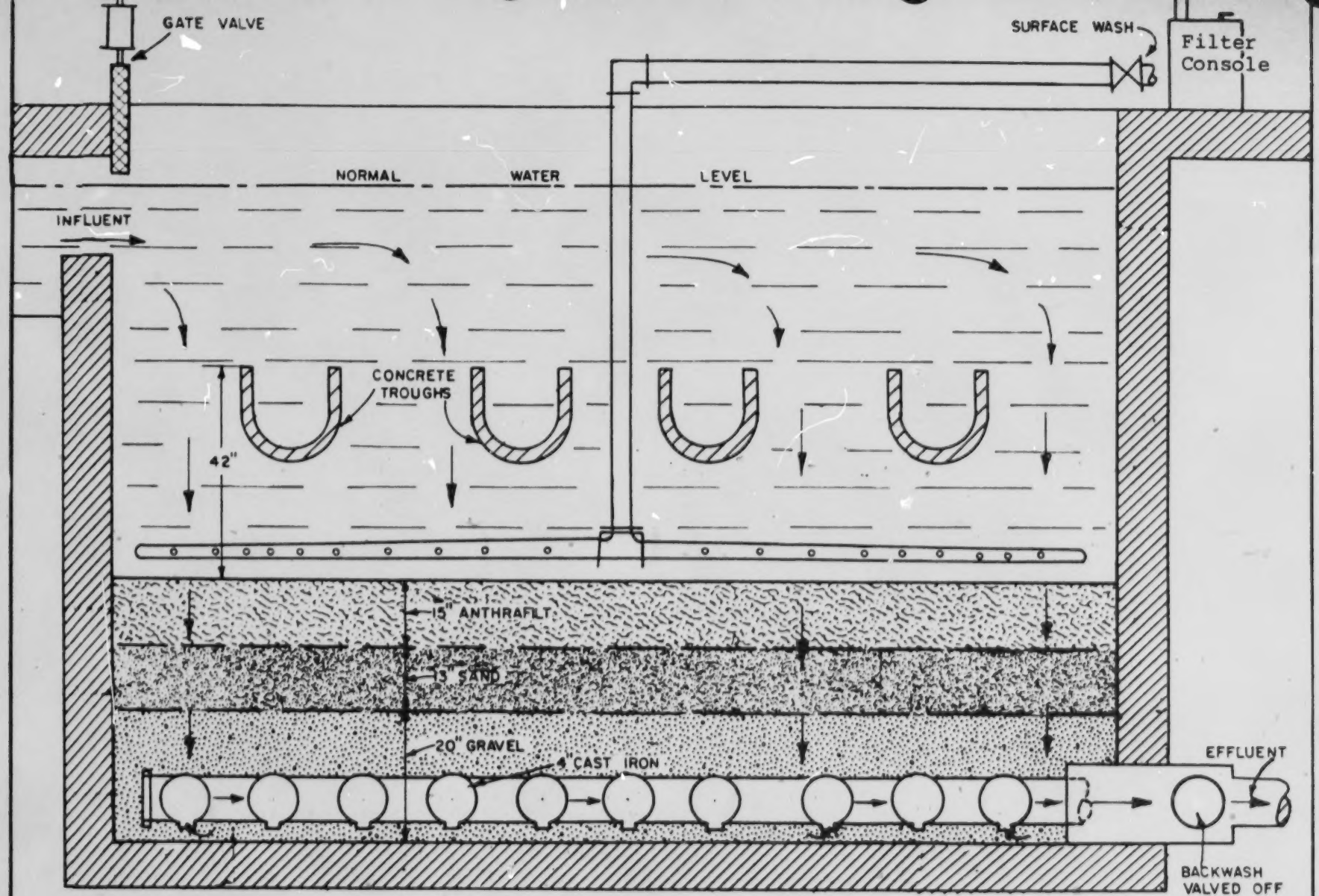


FIG. 5-3

FILTER IN OPERATION

NOT TO SCALE

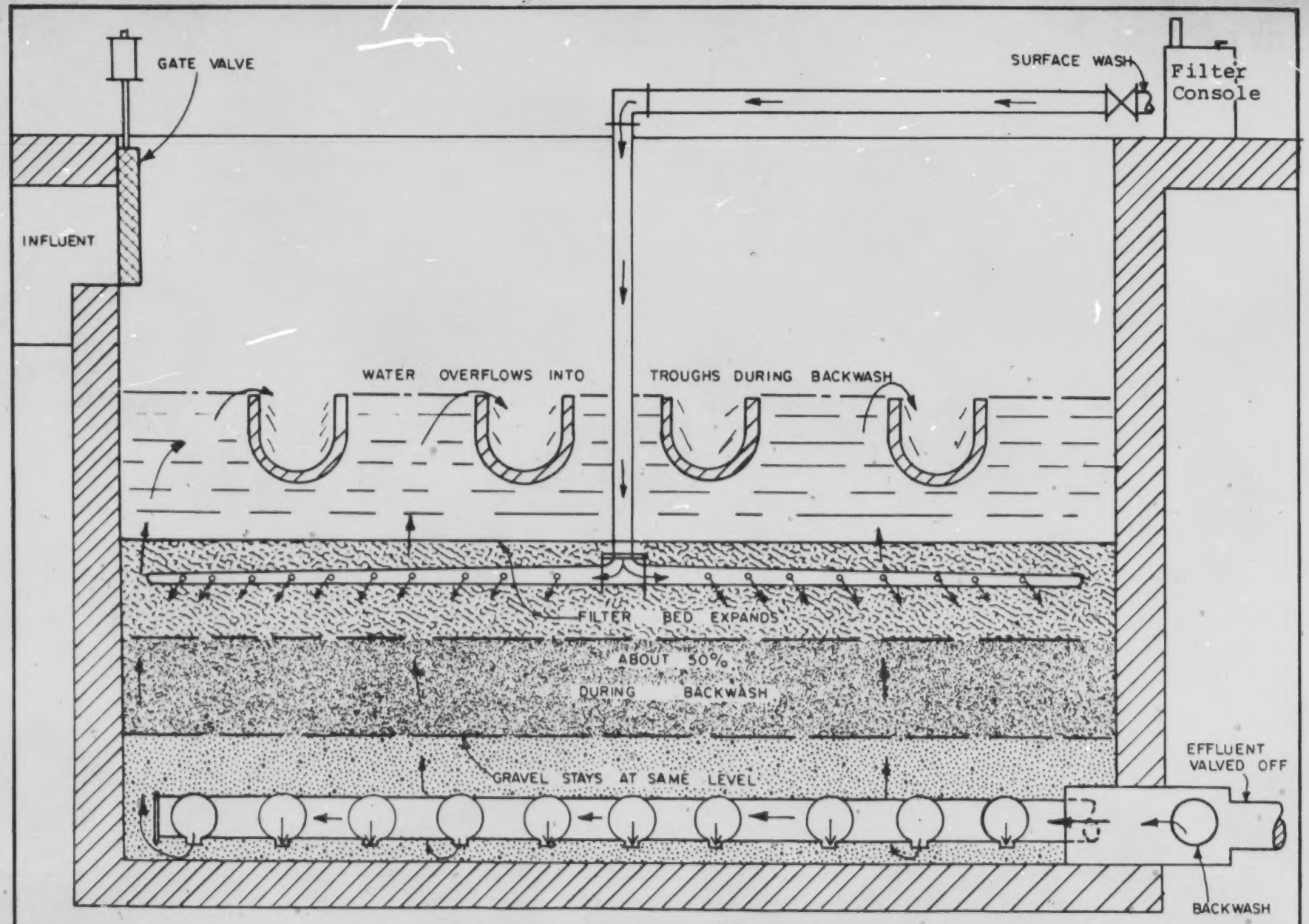


FIG. 5-4

BACKWASHING A FILTER

NOT TO SCALE

Initially the filter media is backwashed at about 6 gpm/sq.ft.(low rate). This is the point at which the particles of media are in effect "weightless" in the filter bed. The Palmer agitator is then turned on and allowed to run for a period of 5 to 7 minutes. The force of the jets of water from the agitator cleans the grains of the filter media and moves them so that the entire bed is gradually turned over and exposed to the jet action. Following this, the backwash rate is gradually increased and the agitator turned off. The filter is backwashed at its normal backwash rate for as long as economically necessary to remove all accumulated turbidity. The water is then slowly turned off and the media allowed to settle before returning the filter back to operation.

AIR WASH FILTER

The air wash filter operates on the following principle:

Washing with Water and Air Scour

In this system, a flow of water slowly rises through the mass of sand. At the same time, air is evenly distributed up through the sand causing considerable turbulence in it.

If the filter is washed and closely examined, it will be found that the sand is not really stirred up. The sand mass remains more or less in place. It has been, however, subjected to a vibration caused by the passage of a large number of air bubbles. The vibration removes the impurities and carries them off with the wash water.

Furthermore, the gravel support layers are unnecessary and should be omitted or reduced to a small layer of coarse gravel to prevent it from mixing with the filter mass by the energetic action of the injected air.

This washing system allows a larger grain size to be used. There is no longer a need for surface washing and sand expansion indicators. The washwater rate can be determined as required and washing operations are carried out without supervision. This facilitates automatic operation.

OPERATING PROBLEMS OF A FILTER

The operating problems of a filter can be divided into two categories:

1. mechanical failure of controls and equipment
2. failure of the filter due to improper pre-treatment or operating procedures.

When seeking the causes of filter bed failure, look for:

1. *Clogging* the filter media by turbidity accumulation. This is caused by incomplete removal during the backwash operation.
2. *"Cracking"* or contraction of the bed. This results from too long a filter run. The filter media gets too dirty and can pull away from the filter wall. This allows untreated water to penetrate to the lowest layers of the filter bed.
3. *Mud Balls* - Tiny balls of accumulated turbidity bind together with particles of filter media. As these mud balls increase in size, they become heavier than the filter media and will gradually sink down to collect on the top layer of gravel.
4. The *shifting and intermixing* of the gravel layers- this problem occurs primarily in the fine gravels located in the top of the support bed. It is caused by uneven backwashing, rapid change in flow rate, a clog or break in the underdrain system.

CORRECTIVE MEASURES

In some cases, the problems are not necessarily due to the operation of the filter itself. *Filter clogging*, for example, is frequently caused by inadequate pretreatment.

Cracking or contraction generally results from either inadequate backwashing or over-running the filters. Loss of head is one indicator as to when backwash is required; the other is the amount of turbidity in the effluent.

Adequate backwashing in every filter operation is extemely important. *The backwash flow rate should be as high as possible without losing filter media.* The backwash should be carried on until the filter media is substantially cleaned. No media will every be absolutely clean, regardless of the extent of the backwash.

FILTER MAINTENANCE

Filter Controls and Equipment Maintenance

There are many and varied types of equipment to be maintained in connection with filters. These include: hydraulically or pneumatically operated gate valves, butterfly valves, sluice gates, rate of flow controllers, surface wash equipment, instruments for filter operation (such as loss of head and rate of flow gauges, as well as the gauges used for indicating and recording the wash rates). *A good preventive maintenance program is essential.*

If you have a full and complete record of past troubles and breakdowns, including the repairs necessitated, a periodic review of such records will alert you to possible future trouble spots. Also, keep enough spare parts on hand to limit any downtime resulting from a breakdown of equipment and have the proper facilities and tools for repairs.

The *operating cylinders* on the various *valves* (influent, effluent, wash, and waste) need periodic checking to replace the gland packing and occasionally to replace the cup leathers on the piston.

The *surface wash equipment* requires little maintenance except for occasional cleaning of the jets on the agitator arms. If the filter media is anthracite some fine grains may become lodged in the jets but it is a simple matter to unscrew these for cleaning. *Even though this is a minor maintenance chore, it should be done periodically, because the agitator arms will not perform effectively if a number of jets become clogged.* The ball bearings on which the agitator arms rotate give very little trouble and so do not require special attention.

The maintenance of the filter bed itself involves a periodic *"probe" check* of the media to determine the contours of the pea gravel layer. This should be done twice a year.

To do a "probe" check, sketch an outline of the filter area. Drain the water from the filter to be checked. Walk along the wash troughs and thrust a six or seven foot length of steel rod down through the filter media until you feel the bottom of the rod come into contact with the pea gravel. Check a marker near the top of the rod against the lip of the wash trough to determine the depth of the gravel at that point. Enter the reading obtained by the "probe" at the appropriate point on the sketch of the filter area. Repeat over the whole bed to obtain an accurate picture of the gravel contour. If undue "humping" of gravel is found in any part of the filter, the sand anthracite must be removed from the area and the pea gravel re-graded and levelled.

Instrument Checking and Maintenance

The filter console gauges are usually for *loss of head and rate of flow.* These instruments will provide continuous accurate readings only if they are given periodic calibration checks and maintained in good condition. No matter how sophisticated the instrumentation, do the following to determine their accuracy:

1. *To check the actual loss of head* through any filter, obtain a length of polyethylene tubing, ¼" or 3/8" diameter, pass one end down to the pipe gallery floor from the filter console above, connect the tubing to a centre tap on the filter effluent line and open the tap allowing water to rise in tubing. The distance from the level of the water in the filter to the level of the water in the tube is the actual loss of head across the filter at that particular moment. If the indication on the filter gauge console does not agree with this value (plus or minus the allowable tolerance) the gauge reading is incorrect. Maintenance is required to correct the situation.

2. *To check the actual rate of flow* through the filter, use a "Hook Gauge". It is very accurate. A "Hook Gauge" consists mainly of a supporting member (1/8" x 1" scrap iron or similar) about 48" long to which to which are fastened two small brackets. On each bracket is positioned a ¼" x 1-1½" brass machine screw which has been ground to a needlepoint at one end. The pointed ends of the brass screws are held in the vertical position by the small brackets and lock nuts. These two "points" on the hook gauge can be positioned so that the distance between points is exactly six inches or 1 foot (whichever is preferred). A stop watch is used with the hook

gauge. In use, the top end of the scrap iron is bent at right angles and the gauge is lowered into the filter, between any two wash troughs. To check the actual filter rate, close the filter influent valve leaving the effluent valve open. Watch the water dropping in the filter and when the water just "breaks" the top point of your gauge, start the stop watch. Stop the watch exactly at the point where the dropping water just "breaks" the bottom "point" of the gauge. The time taken for the filter to pass either 6" or one foot of water in a given period is determined accurately. Knowing the filter area, the rate can be calculated in millions of gallons per day (MGD), which is indicated on the console instrument. A very accurate check is obtained on another aspect of the filter, because a given volume of water passing through the filter in a given time is measured and determined. Allowances must be made for the space occupied within the filter by such accessories as wash water troughs and gully walls, and whether the time is checked with the water level above the troughs or below them.

PRESSURE FILTERS (See Figure 5-5)

There is relatively little difference in the design of gravity and pressure filters as far as the internal components are concerned. There is one very large difference in their *operation*, however: a gravity filter only has a pressure of approximately 8 feet of water on it; the pressure across the bed of a normal pressure filter can be as high as 60-70 psi. It is therefore possible to "drive" or "push" the water through these filters.

Since is it is generally not feasible to provide

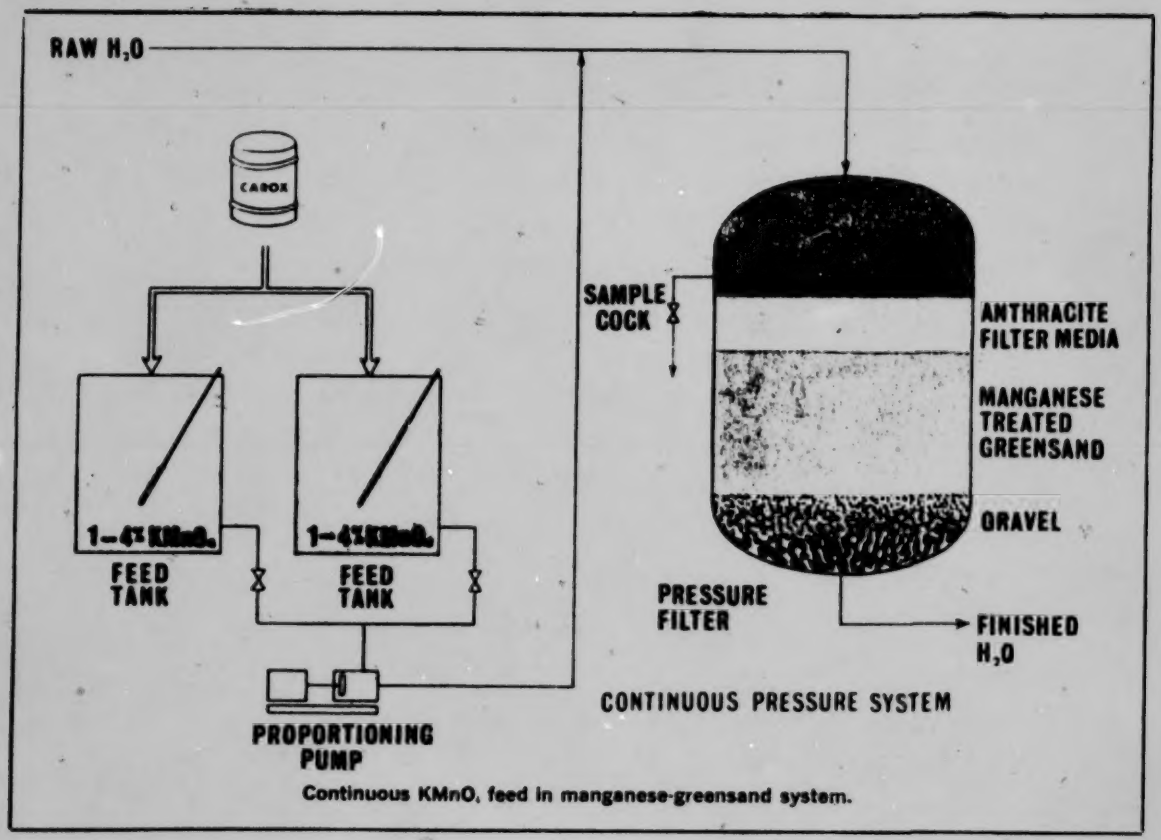


Figure 5-5 Pressure Filter

large vessels equivalent to the capacity of the flocculation and sedimentation chambers of a conventional plant, it therefore becomes quite difficult to provide both adequate settling and transfer of water from the effluent of the settling basin to the filters. This transfer, in the case of a pressure filter, requires more vigorous pumping rates at a higher pressure than on a rapid sand filter. The pumping process would cause a break up of the floc particles resulting in a much deeper penetration of the filter and less filter efficiency. The in-line application of coagulant such as alum is generally not satisfactory, and lends itself to only a very limited number of water sources to be treated. Coagulant aids (polyelectrolytes) are a great help when applied to pressure filters, as they can be used for in-line application. Application is achieved by use of an in-line flash mixing device and a subsequent rapid floc formation results.

Since the sand bed cannot be seen during the backwash period (and this is one of the main disadvantages of such a unit from the operator's viewpoint) the best procedure is to provide a sample stream which can be examined continuously during the backwash and ensure that the rate of flow will not backwash the filter media out of the unit. From time to time, however, it is necessary to increase the backwash rate to a point where a small amount of media is being lost. This determines that the unit is being backwashed at the maximum possible rate. All these difficulties can be overcome through the installation of proper controls, so pressure filters of either the vertical or the horizontal type can be used to good advantage in small installations where gravity filters are too costly.

DIATOMACEOUS EARTH FILTER

Diatomaceous earth filters can be described as filters in which the filtering media is discarded along with the accumulated turbidity. Diatomaceous earth is a natural occurring material composed of the fossilized skelton remains of microscopic algae known as diatoms. Each tiny diatom is a very porous structure of almost pure silica and therefore makes an ideal filter media. There are a few diatomaceous earth filters installed in the Province for the treatment of water. These filters are generally limited to those waters which have little turbidity. The filters themselves are either of the pressure or the vacuum type; in either case, the water is clarified by passing it through the diatomaceous earth. Diatomaceous earth is held on a fine mesh fabric or screen (called septum) by the pressure of the water passing through it. Diatomaceous earth removes the turbidity from the water by filtration. Turbidity accumulates in the coating or "cake".

In the operation of the filter, a small amount of the earth is circulated through the filter and accumulated on the spetum, building up a thick cake known as a *pre-coat*. The raw water is then fed to the filter. A small amount of additional diatomaceous earth is mixed with the water. This added portion is known as the *body feed*. There is a continuous accumulation on the septum consisting of a mixture of turbidity and diatomaceous earth. Since diatomaceous earth is by nature porous, the rate of pressure build-up can be controlled by varying the amount of body feed as required. The limit of filtration is governed by the pressure loss across the filter; a pressure loss of 30 psi across the filter is not uncommon in pressurized systems. When the maximum allowable pressure has been reached, the direction of water flow is reversed and the accumulated diatomaceous earth and turbidity is flushed to the drain. A new precoat is

installed on the septum and the filter is ready for a new cycle. Like the pressure filters, this type of system has only proved competitive from a cost standpoint on the small systems.

DIRECT FILTRATION

Although we have been discussing filters that operate on water treated by coagulation and sedimentation, in some installations this is neither necessary, nor practical. In many locations, the turbidity of the water is sufficiently low so that the filters can be operated without sedimentation. The alum is applied to the water through a mixer, followed by 10 to 15 minutes of flocculation. All the turbidity, plus the coagulant which has been added, is applied directly to the filter. This is done to filters which contain either dual or mixed media, because only this type of filter media has enough room to store the large amounts of solids applied to the filter and still get reasonably long runs. This type of filter is generally limited to those waters whose maximum turbidity will not exceed 40 TU and whose average turbidities are down in the range of 5 to 12 TU. Either gravity or pressure filters can be used.

SUBJECT: WATER TREATMENT OPERATION

TOPIC: 6 Chlorination

OBJECTIVES:

The trainee will be able to:

1. Recall the purposes of chlorination;
2. Recall the purpose of MOE Bulletin 65-W-4;
3. Recall the criteria for chlorination equipment required in a water treatment plant; (See Bulletin 65-W-4)
4. Recall routine operation to follow in chlorination (See Bulletin 65-W-4);
5. Determine the procedures for Emergency Operation;
6. Determine the procedures that may be required if adverse results are obtained from bacteriological samples.

PURPOSE

Chlorination may be performed at a water or wastewater treatment plant for many purposes but the most important is *disinfection* of the plant effluent. When effluents are discharged to bodies of water or water distribution systems, treatment for the destruction of bacteria and viruses is required to minimize the health hazards. Such treatment is known as *disinfection*. The amount of chlorine necessary to obtain a satisfactory reduction of bacteria will vary greatly with the composition of the influent and/or the degree of treatment the plant provides. The selection of the appropriate disinfection procedures is based on the results of bacteriological tests and other evaluations of the total system.

PROPERTIES OF CHLORINE

Chlorine is a greenish-yellow gas with a penetrating and characteristic odour. It is 2½ times heavier than air, and one volume of liquid chlorine equals 450 volumes of chlorine gas. It can be compressed into a liquid which has a clear, amber colour. At -35°C it has zero vapour pressure. However, as the temperature rises so does the vapour pressure and at 20°C it is 82 psi gauge pressure. This characteristic has to be considered when

1. feeding chlorine gas from a cylinder,
2. dealing with a leaking cylinder.

Chlorine has a high coefficient of expansion. For example, a temperature rise of 25°C (from -5°C to 20°C) will increase the volume by approximately 85 per cent. Such an expansion could easily rupture a cylinder or line if it is full of liquid chlorine. This is the reason for the regulation that all chlorine containers must not be filled to more than 85% of their volume.

Chlorine by itself is non-flammable and non-explosive, but it will support combustion.

TABLE 6-1

PROPERTIES OF CHLORINE
Greenish-Yellow Colour
Heavier than Air
High Rate of Expansion
Moderately Soluble in Water
Non-Flammable and Non-Explosive
Supports Combustion at High Temperature

Chlorine does not kill bacteria and viruses directly but, when chlorine gas and water are mixed together in the chlorinator, hypochlorous acid, a strong oxidizing or disinfecting agent is formed.

Chlorine is a surface-active agent and there is a reasonable chance that bacteria hidden within solid particles will not be killed by chlorine. For this reason, chlorine is added for disinfection purposes at a point *after* solids removal. In water treatment, turbidity removal is important because *bacteria can be concealed within the turbidity particles and be inaccessible to the effects of chlorination.*

REACTION OF CHLORINE

Chlorine is an extremely active chemical that will react with many compounds to produce many different products. Such reactions complicate the disinfection process because the chlorine demand of these materials must be satisfied as well as those associated with the disinfection reactions. The quantity of both organic and inorganic substances in the influent varies from place to

place and from time to time, so the amount of chlorine to be added will also vary. Sufficient time (contact time) must be allowed so that there is complete reaction of the chlorine with the chemical and bacterial pollutants as chlorine is added to water or wastewater. The reactions proceed generally as follows:

1. If chlorine is added, it will first react rapidly with reducing compounds such as hydrogen sulphide and ferrous iron. No disinfection results.
2. As more chlorine enters solution, it will react with all of the reducing compounds and organic matter present, forming chloro-organic compounds, which will have a slight disinfecting action.
3. Chlorine added in excess of that required by Steps 1 and 2 will react with ammonia and other nitrogenous compounds to produce *chloramines.*

The chlorine used by these organic and inorganic chloramines reducing substances (Steps 1 and 2) is known as the chlorine demand.

The chlorine used by ammonia and the nitrogenous compounds is known as the combined residual (Step 3).

The combined residual (chloramines) has a disinfection capability but is slow acting and requires a long retention time. To reduce retention time and increase disinfection efficiency, chlorine in excess of that required in Steps 1, 2, and 3 above can be added. This will destroy most of the chloramines (Step 3) depending on the amount added. *If chlorine is in excess of that required to destroy the chloramines, it forms hypochlorous acid or hypochlorite ions. This is known as free residual chlorine. (Breakpoint Chlorination)*

Total Residual Chlorine is combined residual plus free residual.

Chlorine dosage is chlorine demand plus total residual chlorine.

Combined vs. Free Residual

Whether combined or free residual chlorination is practiced depends on a number of considerations.

1. Combined residual chlorine is the method of choice when

   a) long contact time is afforded

   b) high and enduring residuals are desirable

   c) control of algae, aftergrowths and red water in the distribution system is necessary

   d) chlorine taste and odour must be prevented or minimized.

2. Free residual chlorine is the method of choice when

   a) water quality is poor

   b) short contact times exist

   c) there are high concentrations of iron, manganese and colour

   d) difficult tastes and odours must be minimized.

In Summary:

The amount and type of chlorine residual used is controlled by:

1. *degree of chemical and bacterial pollution,*
2. *contact time in the plant beginning with the application of chlorine to the moment it reaches the first consumer or receiving body of water. For effective disinfection, always add chlorine at a point where complete mixing will occur. A minimum contact time of 15 minutes is recommended.*

Other Uses of Chlorination

While the principal purpose for chlorinating water supplies is disinfection, it serves other purposes:

1. Control of taste and odour problems when free or combined residual chlorination is practised. If too little chlorine is added, the taste and odour problems may become severe.
2. Oxidation of manganese, nitrites, and ammonia, or the destruction of phenols and the removal of algae and slime growth.

Ministry of the Environment Chlorination Objectives

The Ministry of the Environment (Bulletin 65-W-4) has set minimum objectives to be used by Ministry plants for chlorination of public water supplies. These objectives are set up on the broadest concept to protect the maximum number of consumers at any one time. Occasionally these minimum objectives will have to be *exceeded* in water plant operating practice and a higher residual may have to be used. A copy of the Bulletin is at Appendix 1.

An operator can follow the guidelines in meeting the minimum objectives, but still produce a water contaminated with coliform bacteria. In these cases, public health is in danger. Immediate changes in the chlorination program must be made, such as:

1. increase the chlorine residual,
2. change the type of residual,
3. change the point or points of application,
4. increase the contact time between point of application and the first consumer.

The water utility is an industry and certain quality control measures are required. One of these is the chlorine residual analyser and recorder (See Topic). This equipment must be kept in proper operating order. The record of chlorine residual provides the operator with positive proof of the degree of performance.

The chlorine residual must be checked and recorded at least once every 8-hour shift. The residual is always maintained at or above the minimum required for the plant. See Para. 3.1 of Appendix 1 for recommended chlorine residuals.

pH AND ITS EFFECT ON CHLORINATION

The pH of a water is an indication of its acidity or alkalinity. It can be lowered to corrosive levels by the addition of chlorine, alum and other coagulants. In some cases, the pH of the raw water may already be too low. Regardless of the cause of low pH, it should be corrected to prevent corrosion by adding an appropriate alkali before the water goes to the distribution system. *All chlorine compounds are most effective in bacteria and virus destruction at low pH.* Any pH correction upwards (above 7.5) should be done *after* the chlorine has done its work.

IMPORTANCE OF TURBIDITY REMOVAL IN WATER TREATMENT

In the chlorination of water, no mention is made of the effects of turbidity because it is assumed that the water meets the turbidity requirements of 1 unit maximum. However, *bacteria can be concealed within the turbidity particles and be immune to the effects of chlorination.* Turbidity removal improves the appearance or clarity of the water and prevents the accumulation of mud in the distribution system. However, turbidity removal is also very important because it eliminates "chance bacteria contamination" as well.

CHLORINE RESIDUAL DETERMINATION

Four common methods for determining chlorine residual in water are:

1. Orthotolidine (OT)
2. DPD Method (Palin)
3. Amperometric Titration

The test procedures for OT, DPD and Amperometric titrator are detailed in Topic 14.

Orthotolidine (OT) Test

The OT method is an old one dating back to 1914, and is still used in most plants. It is good for determining total chlorine residual but the free chlorine residual results obtained are only accurate if the water being tested is near $0^{\circ}C$. Nitrites, iron, and highly oxidized manganese can cause a false colour. The OT method is being replaced by the DPD and the Amperometric methods in water plants. However, a check control is usually maintained with the OT method, especially in the case of the latter method.

DPD (Palin) Method

The DPD method is judged the best colorimetric method for free chlorine in water.

Both free and combined chlorine residual can be analyzed by this method. Differentiation between the free and combined forms of chlorine residual simplify the control of modern chlorination processes.

A novel feature of the Lovibond Comparator method lies in the use of compressed tablets, which are more convenient to use, and permit a procedure of exceptional simplicity.

Amperometric Titration Method

The most accurate method of measuring free and combined chlorine residuals is by the Amperometric titration procedure. This method uses an electric current measuring device to indicate when the chlorine or chlorine indicator has been removed by a titration process.

Phenylarsene oxide is the reducing agent normally used as the titrating agent. It reacts with free chlorine residuals at pH 6.5 to 7.5 in a quantitative manner.

By conducting a two-stage titration with the pH adjusted at about 7 and then at about 4, free and combined chlorine residuals can be measured separately. Interference from nitrites and oxidized forms of manganese are eliminated by conducting the titrations at pH levels above 3.5.

O N T A R I O

MINISTRY OF THE ENVIRONMENT

CHLORINATION OF POTABLE WATER SUPPLIES

Technical Bulletin 65-W-4

Revised September, 1973

CHLORINATION OF POTABLE WATER SUPPLIES

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1.0 INTRODUCTION

1.1 Purpose of Bulletin

To provide a minimum standard of design and operation of chlorination facilities. New installations should meet the criteria as set out in the bulletin and existing facilities are to be brought up to standard in a reasonable length of time.

1.2 When Disinfection Required

Treatment by continuous and adequate disinfection is required when the supply is obtained from a surface source; when the supply is exposed to contamination during treatment; when ground water sources are or may become contaminated, as in fractured limestone areas; or where local conditions, such as flooding, indicate the need.

2.0 EQUIPMENT

2.1 Capacity

Chlorination equipment shall have a maximum feed capacity at least 50 per cent greater than the highest expected dosage required to provide a free chlorine residual. In addition each gas chlorinator not supported by additional standby units of equal capacity shall have a conversion kit sized to double the capacity of the machine.

2.2 Chlorinators and Controls

Dependable feed equipment, either of the gas feed or positive displacement solution feed type, shall be used for adding chlorine. Automatic proportioning of the chlorine dosage to the rate of flow of the water treated shall be provided at large plants and at all plants where the rate of flow varies without manual adjustment, or operation, of valves and/or switches.

2.3 Duplicate Equipment

Chlorine feed equipment at plants providing chlorination to ensure the safety of the supply shall be installed in duplicate, to provide uninterrupted operation of equipment during times of breakdown. In addition, spare parts consisting of at least the commonly expendable parts such as glassware, rubber fittings, hose clamps, and gaskets, should be provided for effecting emergency repairs.

For a multi-well supply system requiring chlorination for disinfection, the standby requirement may be met by one portable unit.

2.4 Weigh Scale

When gas feed chlorinators are employed, a set of corrosion resistant scales should be made available for weighing the chlorine cylinders serving each operating chlorinator.

2.5 Hypochlorite Solution

Where a powdered product is used, hypochlorite solutions shall be prepared in a separate tank. The solution is allowed to clarify before it is directed to the solution storage tank serving the hypochlorinator.

2.6 Safety Equipment (Gas application only)

Each plant shall have readily available, a self-contained or air-supplied type of respiratory protective equipment. Smaller installations may make arrangements with a local fire department or other agency for the loan of the required equipment on an emergency basis with a canister type mask being located at the plant.

When a canister type mask is used in place of a self-contained or air-supplied unit the operators must be made fully aware of its limitations and the location of the more adequate equipment.

One respirator shall be immediately available, located in a conspicuous location outside the area of probable contamination.

Protective clothing including gloves, goggles and safety shoes shall be available for persons handling chlorine.

Eye wash fountains shall be available in case of accident.

Preferably weigh scales for 150 pound cylinders shall be recessed in the floor

Safety chains shall be used to retain 150 pound cylinders, either in storage or on weigh scales, in a safe upright position.

2.7 Building Detail (Gas application only)

Gas chlorine equipment - chlorinators, weigh scales, chlorine cylinders - must be located in an isolated building, room or rooms. In larger installations the storage and scale facilities should be in a room separated from the chlorinators. The construction of the room or rooms should be of fire resistant material and have concrete floors.

Ton cylinders shall be stored on their sides on level racks, between four and eight inches off the grade. Chlorine should not be stored below ground level and the cylinders must be protected from excessive heat, dampness, and mechanical damage.

Areas containing chlorine or chlorinator equipment shall be clearly marked "DANGER! CHLORINE STORAGE" or "DANGER! CHLORINE FEED EQUIPMENT" as applicable.

The exit doors shall be hinged to open outwardly. There shall be two or more exits if the distance of travel to the nearest exit exceeds 15 feet. In each case, one door should be on an outside wall.

Continuous mechanical ventilation at the rate of three air changes per hour shall be provided, or screened openings to the outdoors shall be provided within six inches of the floor in the ratio of one square foot per 500 square feet of floor area. Similar openings shall be provided in or near the ceiling. The openings shall be distributed to produce the maximum air circulation across the floor. Secondly, provision for emergency mechanical ventilation should be made sufficient to produce 30 air changes an hour taking suction at a maximum of three feet above floor level.

Th temperature in the storage and scale room shall not be higher, and preferably slightly lower, than that in the chlorinator room. The gas lines between the scales, chlorinators and injectors shall not be located on an outside wall or in a location where low temperatures may be encountered.

2.8 Testing Equipment

All installations must be equipped with a permanent standard chlorine residual comparator test kit. When free residual chlorination is mandatory an amperometric titrator is also required.

In larger installations, or where poor raw water quality and/or minimum supervision indicates a hazard, an automatic residual analyzer and recorder is required. The chlorine residual recorder shall be equipped with a low residual alarm and installed to measure the chlorine residual in the water leaving the plant.

3.0 ROUTINE OPERATION

3.1 Chlorine Residual

For complete water treatment plants which effect both pre- and post-chlorination, or when a minimum of two hours contact time is assured before distribution after the application of chlorine, or for ground or protected surface water supplies, proven to be materially free from bacterial and viral contamination, the minimum chlorine residual shall be 0.2 mg/l. For all other water supplies the minimum chlorine residual shall be 0.5 mg/l.

The chlorine residual test is performed on a sample of the plant or pipe line-effluent, after it has been held for 15 minutes.

When ground water sources are proven to be free from possible viral and/or bacterial contamination they may be exempted from chlorination.

As circumstances demand the minimum requirements for chlorine residual may be increased.

A free residual chlorination program may be made mandatory, depending on the source of supply and treatment works, and it is a preferred method of treatment.

It is suggested that a chlorine residual be maintained in all active parts of the distribution system.

The selection of appropriate disinfection procedures are contingent upon the results of bacteriological and other evaluations on the total water system including the source of supply.

3.2 Chlorine Application Points

Where possible pre- and post-chlorination shall be practised. When only post-chlorination is possible free residual chlorination should be considered, and a minimum contact time of 15 minutes, before the first possible consumer, shall be provided at all times.

3.3 Chlorine Residual Test

The following procedure shall be followed in performing the orthotolidine chlorine residual test.

1. Draw sample of chlorinated water. The tap should be kept running continuously or for a few minutes before taking the sample.

2. Allow sample to stand for 15 minutes to simulate the required minimum contact period.

3. Use 0.5 ml of orthotolidine (O.T.) reagent in 10 ml cells, 0.75 in 15 ml cells, and five ml in 100 ml tubes. Place reagent in testing tube; add sample to required volume; and mix. When the temperature of the sample is less than 68°F bring it to that temperature quickly after mixing with the O.T.

4. A colour comparison is made when the maximum colour develops.

5. The test results are recorded in the plant records and any necessary alteration is made to the chlorine application rate.

The above procedure is satisfactory for determining the total available chlorine residual. When the free residual is required the sample must be near 32°F when the O.T. is added and the colour comparison is made immediately. The orthotolidine arsenite (O.T.A.) test can also be used to determine the free available chlorine residual.

The accuracy of an automatic chlorine residual analyser shall be checked daily. This is accomplished using either the amperometric titration or orthotolidine colourimetric test procedures. The results of the check are inscribed on the recording chart along with the date and operator's initials, opposite a mark showing the time of the check.

The chlorine residual test must be performed frequently enough to ensure that an adequate chlorine residual is maintained at all times. Such points as raw water quality and a resultant variation in chlorine demand, and changing flow rates must be taken into consideration. When a residual analyser alarm system is used the testing frequency may be reduced.

3.4 Records

Minimum records shall include:

1. daily records of the chlorine used and scale readings,
2. results from all chlorine residual tests,
3. the flow rate and chlorine feed rate at the time of testing,
4. water used and chlorine dosage in mg/l on a daily basis,
5. detail on chlorine cylinder changes, orders and chlorine on hand, and
6. monthly and yearly summaries of chlorine consumption and feed rates.

4.0 EMERGENCY OPERATION

Where chlorination is required for disinfection purposes a continuous feed of chlorine must be assured. For this type of service the operating authority shall develop a standby operating procedure to cover emergencies. The procedures developed shall be posted in a prominent location in the plant and all operators shall be made aware of the information thus given.

The emergency information shall include:

1. the order not to pump unchlorinated or inadequately chlorinated water to the distribution system,

2. the name, address and telephone number of -
   (a) senior supervisory personnel,
   (b) medical officer of health,
   (c) Ontario Ministry of the Environment,
   (d) chlorinator service company, and
   (e) chlorine supplier,

3. the order to notify the Ministry of the Environment, and the medical officer of health immediately if unchlorinated or inadequately chlorinated water is directed to the distribution system,

4. details on emergency chlorination procedures,

5. a statement on operator responsibility, and

6. details on announcing a "Boil Water Order" (developed with MOH).

When emergency chlorination is provided the chlorine residual in the water leaving the plant shall be 1.5 mg/l.

When unchlorinated or inadequately chlorinated water has been directed to the distribution system, and until direction is obtained from the Ontario Ministry of the Environment, the chlorine feed rate shall be increased and a program of hydrant flushing initiated to provide a chlorine residual of 1.0+ mg/l in the whole of the distribution system. When increasing the chlorine residual or carrying out an extensive hydrant flushing program, notify all customers who may be adversely affected.

5.0 ADVERSE BACTERIOLOGICAL RESULTS

When the results from bacteriological samples collected from the distribution system do not meet the requirements of the Ontario Ministry of the Environment Drinking Water Objectives, the Ontario Ministry of the Environment and the local medical officer of health shall be notified. The Ministry will recommend corrective action suited to the individual circumstances. The recommendation may include one or a number of the following procedures:

(a) the disinfection, for a 24-hour period, of the distribution system with a solution having a starting strength of 50 mg/l of available chlorine;

(b) the initiation of chlorination procedures on an unchlorinated supply;

(c) an increased chlorine residual requirement together with a distribution system flushing and/or swabbing program;

(d) the collection of further samples;

(e) a recommendation to the medical officer of health that a "Boil Water Order" be issued.

6.0 DISINFECTION OF NEW WORKS

6.1 Preparation

Before disinfection is attempted, all surfaces must be thoroughly cleaned. Pipe lines are flushed with potable water until a "turbidity-free" water is obtained at all ends. Where possible foam swabs should be used to assist cleaning. Reservoirs are to be brushed as required, to obtain clean surfaces, and disinfected as per AWWA Standard D 102-64 or equivalent.

As chlorine is a surface active disinfectant it may not penetrate crevices or particles of debris. Therefore, a thorough cleaning is necessary if the disinfection program is to be effective.

6.2 Disinfection

Disinfection may be accomplished by one of the following procedures.

1. In mains all surfaces shall be in contact, for a period of 24 hours, with a chlorine solution having a starting strength of 50 mg/l. If a residual of less than 25 mg/l remains at the end of the contact period the procedure shall be repeated.

2. In large mains a "slug method" may be used, whereby a slug of water containing at least 300 mg/l of available chlorine is moved through the pipe at a rate such that the chlorine is in contact with the pipe for at least 3 hours.

3. To conserve water and chemical, reservoirs may be disinfected by spraying all surfaces with a chlorine solution havin a starting strength of 250 mg/l available chlorine. Special protective clothing and self-contained or air-supplied type respirator must be used by personnel performing the spray procedure and necessary safety precautions adheared to.

4. When surface conditions are not ideal, such as will be encountered in used works, special disinfection procedures will be required. This could include the maintenance of a chlorine residual for an extended period of time.

6.3 Testing

After disinfection, and when the chlorine residual in the treated works is at or below the normal operating level, bacteriological samples shall be collected. When a 0.2 mg/l or greater available chlorine residual is to be maintained in or after the new works, one set of satisfactory bacteriological results shall be obtained before the system is placed into operation. Otherwise, a minimum of two sets of coliform-free results shall be obtained before the works are placed in service.

SUBJECT:

WATER TREATMENT OPERATION

TOPIC: 7

Care, Maintenance & Operation of a Distribution System

OBJECTIVES:

The Trainee will be able to:

1. Recall problems common to neglected distribution systems;
2. Describe procedures for disinfection of new works as outlined in 65-W-4;
3. Describe routine maintenance required on:

   Valves
   Hydrants
   Reservoirs

4. Describe the methods of leak detection in distribution systems;
5. Recall the common types of cross connections and describe methods of prevention;
6. Recall the methods used for pipe thawing;
7. Describe the procedure for electrical thawing of water mains and services.

CARE, MAINTENANCE & OPERATION OF A WATER DISTRIBUTION SYSTEM

General

Without an adequate maintenance programme, even the best installed systems will deteriorate. Problems common to neglected systems include:

1. Fire hydrants that will not produce the necessary volumes and pressures.
2. Undesirable taste or odours within the distribution system caused by
   a) dead water - dead ending mains
   b) rerouting of water - change of flow direction
   c) lack of a routine flushing program.
3. Leak repair work or maintenance requiring shut off.
4. Reduced water flow caused by incrustations lining the mains.
5. Frequent water main breaks as a result of freezing lines and services.

NEW DISTRIBUTION SYSTEMS

Disinfection

Chlorination of all new works is required; however, it is effective only in disinfecting the surfaces. It does not remove foreign material (occasionally animal or foreign matter is left in the main) during construction. The Ministry requirements for disinfection are detailed in Bulletin 65-W-4.

Lines

New lines must be swabbed or pigged. Although the swab will not move a wood block, the loss of two or three swabs may indicate trouble. The practice of eliminating "pigging" or swabbing the mains to save money is a foolish risk.

All main repair work must be adequately disinfected to ministry standards. No one will object to the generous use of chlorine when disinfecting mains.

Valves

All valves and valve boxes adjacent to or part of construction projects must be inspected regularly during the work to ensure that all conditions are satisfactory. The location of every valve in the system must be itemized on the municipal map.

Valve boxes must be adequately protected from vandalism.

All valves should be closed and opened at least once a year. Since gate valves are constructed of different metals, corrosion can take place on the moving faces unless they are routinely flushed by regular operation. Valve blockages can sometimes be flushed by partially closing the valve, closing an adjacent main valve, and opening a hydrant between the two. All valves should operate in the same direction if possible to avoid damage when an overeager helper tries to open the valve in the wrong direction. Very little can be done to maintain buried valves without excavation.

MAINTENANCE

Pipes

Proper installation can be the best aid to maintenance. Pipes should be laid by hand on the bottom of undisturbed soil in a trench. Main leaks and breaks occur most frequently in the winter when contractions due to cold trouble the system with assistance from:

1. Thin pipe walls as a result of corrosion.
2. Improper bedding allowing pipes to sag. It can cause circular breaks in small pipes and in larger pipes splits result from ring stresses.

3. Metal fatigue from vibration.
4. Water hammer.
5. Construction activity adjacent to the piping.

To Repair:

1. *Circumferential break* - split sleeves.
2. *Longitudinal break* - dewater main and install a new section.

After excavation and repair, back fill using granular material (3/8" crushed stone). At *Rubber Joints* adequate blocking or strapping should be provided at bends, change of direction points, or at end of line.

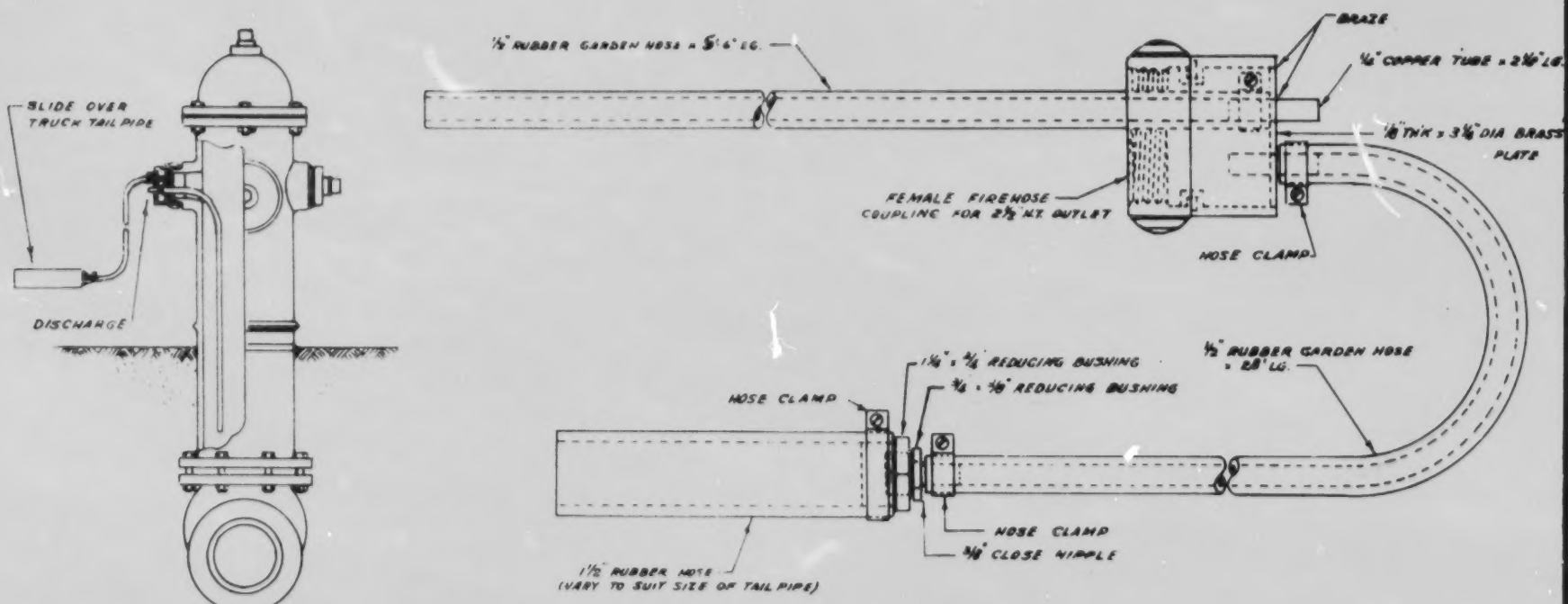
Hydrants

Hydrants are frequently the only portion of the distribution system actually seen by the public and therefore should be kept in good condition and painted. They should be properly drained to minimize chances of contamination or freezing. In areas where high water table floods the hydrant barrel, drains should be plugged and the hydrant pumped dry after every use. Routine pumping should be carried out at problem hydrants to ensure that no damage due to freezing takes place. When self-draining hydrants are in use, hose nozzle caps should not be replaced immediately. Allow the hydrant barrel to drain. (See Figure 7-1 for details of an exhaust powered hydrant pump.)

Antifreeze in the hydrant barrel may enter the water main with a drop in pressure, constituting a potential health hazard. Its use is not recommended.

Hydrants should be checked at least twice every year (Spring and Fall). Items to check include:

1. Stuffing box
2. Valve
3. Valve seat
4. Barrel (for cracks)


SLIDE OVER TRUCK TAIL PIPE
DISCHARGE
½" RUBBER GARDEN HOSE x 5'6" LG.
BRAZE
¼" COPPER TUBE x 2½" LG.
⅛" THK x 3⅛" DIA BRASS PLATE
FEMALE FIREHOSE COUPLING FOR 2½ NT. OUTLET
HOSE CLAMP
½" RUBBER GARDEN HOSE x 28" LG.
1¼" x ¾" REDUCING BUSHING
¾" x ½" REDUCING BUSHING
HOSE CLAMP
HOSE CLAMP
½" CLOSE NIPPLE
1½" RUBBER HOSE (VARY TO SUIT SIZE OF TAIL PIPE)

EXHAUST POWERED HYDRANT PUMP

FIGURE 7–1

5. Drain parts (if in use)
6. Threads
7. Geared opening mechanism and gaskets

Although it may be desirable to use hydrants only for fire fighting, other uses might be allowed for a nominal sum or by payment for the water used. An auxiliary valve should be installed on one of the hose nozzles to permit only authorized personnel to operate the hydrant at the start and end of the required period. This prevents damage from improper and repetitive hydrant operation. They should be opened or closed slowly to prevent water hammer in the rest of the distribution system.

Reservoirs

Elevated storage, stand pipes and ground storage require routine inspection and maintenance to ensure they are not the source of water quality problems and excessive leakage. Tanks and stand pipes should be drained and inspected each year to ensure that severe corrosion does not proceed to the point of failure. Tanks should be cleaned and painted routinely. *Safety regulations governing work in confined spaces must be met at all times.* Ground storage should be emptied and the slime and deposits removed regularly. *The works must be disinfected before being returned to service.*

PROBLEM SOLVING IN DISTRIBUTION SYSTEMS

Taste, Odour and Colour Problems

Problems may be generated:

1. Within dead areas where water becomes stagnant and deoxygenated (flat).
2. When turbidity and iron settle out in the mains.
3. When iron and sulphur bacteria are allowed to build up and cause offensive odours.
4. Through internal corrosive action on mains due to aggressive water (low pH).

A flushing and foam swabbing programme can be of some help in controlling water discolouration. If the programme fails to help, technical aid should be called in immediately.

Adverse Bacteriological Sampling

If the results obtained on routine samples indicate bacterial contamination, *inform the local health unit and MOE nearest Regional or district office immediately.* An intensive resampling program must be instituted to immediately trace the cause or origin of the problem. The operator should:

1. Resample the raw and treated water.
2. Resample the location of the bad sample.
3. Take sample from consumers on either side of bad sample.

On-the-spot chlorination may be necessary if internal contamination has taken place. The location of equipment for use in an emergency should be known to the operator.

Leak Detection

There are two main methods of finding leaks. These may be divided into leaks that one can see, and leaks one can hear.

1. If one sinks up to the ankles in mud in a normally dry section of ground, there must be a source of water somewhere. It should be checked if there is a water main or service nearby. The fact that the surface ground is dry is no proof that there is not a water leak. Water will find the easiest path to escape and sometimes this path is not the obvious one of bubbling up through the surface. This is particularly true during the winter.

When it is snowing, one section of the ground may not have any snow on it, since the water leak raises the temperature of the ground slightly and melts the snow. When the ground is frozen, the water from the leak can travel long distances to find a spot where the frost is not solid. It will then surface at that location.

2. Leaks One Can Hear

a) When listening for a leak, try to remember the big leaks are quiet, and the little leaks sound like Niagara Falls. Slight leaks that don't get any bigger can be tolerated; however, little leaks often wash sand into the leak, wearing the leak larger and eventually causing trouble. *Don't neglect the leaks because they are small.* The really bad leaks are the ones going into sewers or sand, carrying the water away unnoticed. If there is a bad leak, look for the general area by shutting down the mains. This must be done at night. Such a leak can be suspected when pumpage suddenly increases and doesn't drop below a certain level at night or Sunday as normally expected.

b) There are two methods of listening for leaks. One is to use an ordinary metal rod or stick with an ear cap on one end. The end of the rod or stick is placed on any water-carrying pipe and the operator listens. Some people are expert at this simple procedure because they have used it often enough to be able to identify the sound of a leak as opposed to the sound of real water usage. Modern electrical amplifying equipment accomplishes the same result, by allowing more volume. It is often equipped with a meter. The equipment is moved from area to area, usually using hydrants as listening posts, until the area is located

where the noise is loudest. It may be necessary to shut off services at curb boxes to limit the water movement within the area under question until the exact location of the leak is established.

It is important to disinfect all exposed surfaces when repairing leaks and breaks as outlined in Bulletin 65-W-4.

OCCURRENCE OF CROSS CONNECTIONS

The passage of polluted or unsafe water into a water supply system by backflow is known as a *cross connection.* The occurrence of cross connections is not unique in any specific type of plumbing fixture or on any particular premises. The hazards may exist in homes, in public buildings, or may occur on commercial and industrial premises. Some installations vulnerable to cross connections are: water closets equipped with a flushometer, laboratory sinks, steam tables, water cooled apparatus, or any equipment with a submerged supply.

Two common types of cross connections are:

1. Back Flow
2. Secondary Supply Systems

The enforcement of stringent plumbing regulations, however, can be of great help in avoiding the most common cross connections. The Plumbing Code applying to water supply systems is designed, in part, to ensure that active and potential cross connections do not occur. Much can be done to prevent cross connections by observing the following principles of plumbing; the use of air gaps, the effective installation of back flow preventers, provision for fixture overflow, and the use of indirect supplies.

Whenever possible, there must be an air gap between the supply outlet and the flood level rim of the fixture. Unless a back flow preventer is properly installed in the distributing pipe, the orifice of the faucet or spout must be located so that the air gap complies with the plumbing regulations of the Province of Ontario.

PIPE THAWING

Occurrence of Freezing Problems

Since freeze-ups occur in most municipal systems in Ontario, the services of thawing crews are required during the winter months. Apparently, as long as a favourable balance of heat is maintained in the pipeline, freezing conditions will not develop. Frozen services are more common than frozen mains. Less water and longer periods of no motion can cause this. Insulation protects pipes from freezing. Another protection is to bury the pipes below the frost line.

Methods Used in Thawing Watermains

Frozen watermains require the application of enough heat to melt the ice and snow, permitting the water to resume flowing. Many methods have been used, including:

1. Digging down to the pipe and building a fire in the trench over it.
2. Using gasoline or torches.
3. Wrapping the pipe in rags and pouring hot water on it.
4. Using steam.
5. The use of electricity.

Except for the use of electricity, these measures involve considerable time and inconvenience, and are often messy. Pipes may be split from extreme heat when steam or open fire are used.

Electrical Thawing of Watermains and Services

The passage of electrical current through a conductor, whether it is a wire or a pipeline, encounters resistance. *This resistance creates heat*, the intensity depending upon the characteristics of the conductor. This is the principle behind the electrical thawing of pipes. The low melting point of lead indicates the danger of melting lead surface pipes with high currents. Iron lines heat most readily, while copper heats slowly. Whenever lead goose-necks are used, low currents should be employed.

Thawing Procedure

1. Locate the frozen section of pipe.
2. Include the frozen section in an electrical circuit by connecting cables from the source of energy to the closest convenient points in the piping system (hydrants, curb service boxes, etc., or, for service connections, exposed pipes in the house and the service shut-off).
3. Ensure that good electrical connections are made. Remove rough scale at the point where the clamp is to be fastened to the pipe or arcing may cut holes in the pipe.
4. If a house service is involved, remove the water meter from the circuit to break the connection between the service pipe and the house piping.
5. Remove the ground clamp from the water pipe to prevent stray electrical currents getting into the neutral wire and wiring system of the house.
6. Proceed with thawing.

Removal of the meter alone or disconnection of the ground clamp alone is not enough to keep the current from feeding into the house wiring circuits. Use caution. Underground contact of metal pipes or some other circuit may occur.

Some Do's and Don't's on Thawing Frozen Watermains

1. Use the least current possible to do the job. The lower the voltage, the less the chance of injury to persons or property, including piping.

2. Avoid connections which might waste current and prolong thawing. Use only generator sets equipped with meters to determine the exact amount of current used. If the meter does not indicate a current flow, this may be caused by poor connections or bad joints in the pipe, or connections which have been made to different pipe systems. *Make sure that the frozen length of pipe is included in the circuit.*

3. Avoid the possibility of shorts or ground. Current may be fed back through gas services by the water heater. *No gas pipes or furnace support wires should be in contact with the pipe being thawed.* Radio ground wiring should be detached. Heat may be detected by placing a hand on the meter couplings. To play safe, the main switch should be disconnected.

4. Make certain of the pipe material in use and make allowances in the current applied.

5. Make sure the wires from the energy sources are adequate and that a good electrical contact is made. Scraping the pipe surface may be necessary. Distance between the connections should be as short as possible and limited to the frozen piece of pipe.

6. *Open the pipe before thawing.* This will let you know if water is beginning to flow. It also avoids the possibility of steam pressure developing and doing more damage than the frozen line.

SUBJECT: WATER TREATMENT OPERATIONS

TOPIC: 8 Records

OBJECTIVES:

The trainee will be able to recall:

1. the main reasons for maintaining plant records;

2. one method and the reason for maintaining records on the distribution system, i.e. valves, hydrants, booster stations, blow-off valves, etc;

3. the statistical entries that should be recorded on the daily operating sheets;

4. the information recorded in the maintenance log book;

5. information which can be obtained by an analycis of:

   a) daily operating sheets
   b) maintenance Log Book.

RECORDS

PURPOSE

Obtaining and recording information is not an end in itself. Process control test results, together with such data as flow rates, power consumption, quantity of chemicals used, hours of pump operations, recorded in an understandable (and easy to use) form must be analyzed so that the present and future operating requirements can be met. Records provide the means of ensuring proper maintenance schedules are adhered to. They provide a basis for justifying plant expansions and provide the information by which design changes can be instituted. Notwithstanding the overall importance of records, only those that can be useful should be maintained. Records for records sake means a waste of time and labour to the detriment of some important task.

The main purposes for the establishment and maintenance of a system of records are -

1. To assist the operator in solving plant problems.
2. To provide evidence that the plant is meeting the water quality objectives established by the Ontario Ministry of the Environment.
3. To provide the basis for handling complaints.
4. To determine equipment, plant and unit process performance standards.
5. To plan equipment replacement schedules, design changes and plant expansions.
6. To establish a cost base.

RECORD SYSTEMS

Record systems must be set up with two objectives in mind. Firstly, it must be as simple as possible, the form and extent of records being carefully planned. Secondly, a

procedure must be established to ensure continuity of the desired records.

Records should be permanent, with entries made in ink or indelible pencil. Ordinary lead pencil notations smudge easily or can be altered. Once a record has been made, it should be filed in such a manner that it can be easily retrieved.

Plant Operational Records

The data which is recorded at an installation will be determined by the type of treatment plant, the volume of water treated and the kind of installations tied in with the treatment plant.

Records of treatment plant operation may include information on:

1. Filter runs
2. Wash water used.
3. Pumps in operation.
4. Chemical dosage including chlorination rates.
5. Condition of raw and treated water.
6. Flows.
7. Power consumption
8. Results of laboratory tests.
9. Amount of chemicals used.

Source Records

Records should also be maintained for the water source(s). If it is a surface source, information on the following items should be maintained:

1. Raw water temperature
2. Raw water quality (turbidity, colour, taste & odour)
3. Raw water quantity used.
4. Level of water in river, stream or lake.

If the source is ground water, information recorded should include:

1. Raw water temperature.
2. Raw water quality.
3. Well logs.
4. Pumping intervals.
5. Static levels.
6. Drawdown levels.
7. Rate of replenishment.
8. Quantity of water used.

Pumping Station Records

Records for pumping stations should include:

1. Amount of water pumped.
2. Number of hours run by each pump.
3. Power consumption.

Distribution System Records

Strict procedures should be followed in relaying information on the operation and maintenance of *distribution systems* to the plant operator. A large scale comprehensive map is necessary to show all mains, their sizes and types, valves, hydrants, streets, reservoirs, elevated tanks, wells, booster stations and emergency interconnections with other systems, as well as blowoffs, air release valves and normally closed gate valves, if possible.

The original map should be carefully stored and copies issued to operating personnel for their use. As the map must include the entire system, the scale may be too small to show the required detail. Therefore, to have an adequate record, it will probably be necessary to divide the map into sections on separate sheets, using an adequate scale to show the required details. Sectional maps must be

accurately scaled so that adjoining sheets will line up. Information on sectional easements, street names and widths, mains, their sizes and locations, material, year installed, hydrants, their types and classes, details relating to valves, service lines including sizes and locations, and all other information relating to the section of the system under study should be recorded. In other words, the section map is a magnified part of the major system map which enables you to read the fine print. In large distribution systems, it is often advisable to enlarge or divide section maps for works foremen assigned to particularly congested areas.

Sectional maps are among the most important of all distribution system records. Supplements for field crew use are *valve records.* These give complete listings of all gate valves with their locations, functions, and operation. Data covers each valve number, size, make, class, number of turns to open, direction of turns to open, street location, distance and direction from the street line or curb and intersection, or other information to help locate the correct valve quickly.

Accounting Records

All *accounting records* may not come under the jurisdiction of the plant operator, but information that includes inventory control, costs of maintenance and time or payroll data does. The payroll records are highly important to the operator. If they are not accurate, and are not submitted to central accounting on time, he will receive complaints. With the development of machine accounting, many of the major accounting records are maintained in the form of punched cards. Later, they can be used for billing procedures and collection data.

MAINTENANCE LOG BOOK

Records should be kept in a ring binder *log book. Each piece of equipment has a separate page* in this book, with the following information recorded:

1. *work done*
2. *time spent*
3. *costs for any piece of equipment*

The accuracy, usefulness and reliability of the maintenance system depend upon the conscientious completion of this log book. See Figure 8-1.

Information which can be obtained by analyses of records in a log book:

1. *comparison of existing equipment*
2. *major faults and problems*
3. *evaluation of the maintenance system*

4. *evaluation of maintenance and reliability of equipment as a basis for selection of future equipment*
5. *evaluation and comparison of maintenance costs for equipment*
6. *measures of performance and effectiveness of equipment and maintenance*
7. *information for discussions with suppliers and the provision of "feedback".*

Any preventive maintenance system is only a part of the overall maintenance function; its application must be reviewed with this in mind. *An evaluation of the success or deficiencies of the preventive maintenance scheme can be obtained only if total maintenance data is recorded.* The *costs* of preventive maintenance and breakdown maintenance must somehow be *minimized*. To achieve this, complete maintenance data must be available.

There is no magical mathematical formula to establish how much maintenance should be done. Whenever treatment is incomplete, the question to be asked is *"Was enough maintenance done to prevent equipment failure?"*

Not only does *poor service annoy the consumer*, but all water and sewage operators and maintenance personnel have a *moral responsibility* to ensure that the total environment, water quality, and service is not impaired.

Good maintenance in water and sewage works is in the hands of the operators and maintenance personnel.

Equipment Name :
Equipment Number:

DATE		WORK DONE, MATERIALS & CATEGORY	MAN HOURS	CONTRACTOR COST	LABOUR TOTAL	MATERIAL COST	MATERIAL TOTAL

8-7

Figure 8-1 Typical Log-Book Page

DAILY LOG BOOK

Another useful record is the *diary* or *daily log book*. Many miscellaneous incidents in plant operation do not fit into the regular records employed, but they should be kept in some type of permanent form and might include:

- occasional numerical data and measurements
- maintenance items, replacement and repairs
- start-ups
- trouble, and various methods tried for correction in start-ups or treatment
- complaints from customers
- visits by officials and their comments
- reports from other agencies (such as the Ministry of Health) on inspections and tests

and similar facts that an operator always appreciates having on hand. This information may be quickly referred to if the daily summary sheet of operation contains a cross reference. Knowledge of the date of an occurrence, even without further detail, is often helpful.

The records you keep will depend on the type of plant you operate, the amount and category of information you need to answer enquiries, and any information that will help you to operate the plant efficiently and economically. *The important items to remember in record keeping are accuracy and continuity.*

SUBJECT:

WATER TREATMENT CHEMICALS

TOPIC: 9

- Characteristics
- Handling
- Feeding

OBJECTIVES:

The trainee will be able to

1. Name the four (4) classifications under which water treatment chemicals fall.

2. Describe the general storage and handling practice required for chemicals used in a water treatment.

3. Name the chemicals most commonly used in treatment of water.

4. Identify the types (categories) of chemical feed equipment used in water treatment plants.

WATER TREATMENT CHEMICALS

TYPES OF CHEMICALS

Many of the compounds used in modern water treatment plants have appeared in the last 20 to 25 years. Major advances would include the polyelectrolyte coagulant aids, the fluoride agents and chlorine dioxide. Others show a use-renaissance such as granular carbon, potassium permanganate and caustic soda. Still others enjoy, so to speak, a change in use direction, such as sodium silicate, chlorine and granular carbon. Others continue to be the mainstay compounds: alum, chlorine, soda ash, hydrated lime, and powdered activated carbon.

Noteworthy in the improvements affecting the delivery, feeding and storage of these chemical agents are the introduction of aluminum sulphate in liquid form, carbon slurry storage, lime slurries from bulk deliveries of hydrated lime and storage of saturated soda ash slurry in water treatment plants.

The chemicals for water treatment fall into one of the following four types:-

1. "Dry type" include the nonhygroscopic and slightly hygroscopic solids.
2. "Moist" or "Hygroscopic type" includes solids which absorb moisture rapidly.
3. "Liquids" include those materials which are liquid at normal temperature and pressure.
4. "Gases" include gases at normal atmospheric pressure although they become liquid under higher pressures.

Each of the four groups requires different shipping containers or units and different handling. Chemicals used in water treatment are listed in Appendix 1. The characteristics in descriptive sequence are: name of chemical, common names in parentheses, physical characteristics, chemical formula, density, solubility, hazard, basis for purchase.

HANDLING

Greater knowledge of materials together with the availability of new corrosion-resistant materials has facilitated the tasks of both the treatment plant designer and operator. Recommendations for the use of these materials for handling specific chemicals can be obtained, on request, from the manufacturer.

Chemicals for water treatment are shipped in a variety of containers. The choice of most convenient and economical packaging may depend to a large degree upon the extent of use and proximity of the plant to the supplier. There are various types of packaging in general use since manufacturers confine their packaging to chosen types. It is interesting to note the trend towards bulk truck delivery. Basic reasons for this trend include the variety of trucks available, reduced loading costs, improved delivery service, quick unloading, customer preference and resultant saving in chemical and attendant labour costs.

The variety of modern packaging and the different forms of transportation available make appreciable saving possible through selection of the various types. The small plant may not find it possible to accept bulk deliveries, while the moderately sized plant may find bulk delivery economical for some chemicals but not for others and the large plant will find economy in bulk delivery for nearly all chemicals. Size of plant does not preclude the possibility of appreciable saving, particularly where flexibility of chemical handling procedures has been provided in the design of the plant. Use of liquid chemicals in place of dry may prove to be more economical when all the above factors are considered. The cost of liquid chemicals delivered to the water plant may be no less, but there may be appreciable saving in operational costs. Use of unit hoppers for dry chemicals in place of bags eliminates packaging costs and products waste in handling and shipping, and reduces floor space for storage as well as the time and labour in handling.

STORAGE

All handling, storage or feeding areas should be maintained in a clean, dry, well-ventilated condition. Chlorine and other gases (Sulphur dioxide, ammonia) and gaseous products should be housed separately, with exterior vents provided with fans of sufficient capacity to force positive ventilation within a few minutes.

Since chlorine is heavier than air, exhaust fans should draw from near the floor. Ammonia gas is lighter than air, therefore, the exhaust should be from near the ceiling.

Areas for dry chemical storage need ample positive ventilation to maintain dust free air to protect the health of workers and avoid hazards of fire.

Normally dry bulk chemical is stored in bins or silos constructed of steel or concrete, of which there are innumerable designs. When the bins are constructed of steel, excellent control of inventory is provided by installed level indicators.

Another storage method for those chemicals which do not readily dissolve is "slurry storage". This method is particularly popular for activated carbon, and it is utilized somewhat for the calcium lines. Storage tanks for slurry may be lined and this is essential for carbon.

The common designs of storage bins are square, rectangular or round with an inverted truncated pyramid or cone forming the bottom and passing the chemical to the hopper of some type of feeder. The vertical sides of the main body of the bin generally extend upward to provide the required capacity.

Silos are large, cylindrical, freestanding storage units. They are utilized by plants which do not have sufficiently large storage internally, in order to receive bulk chemicals in truck-load quantity, or where the source or the transportation facilities make it necessary to carry a high inventory. They are completely weather-proof and

are provided with conveying and elevating equipment for transfer of the chemicals to the in-plant supply bins. This equipment is generally of the pneumatic type.

SELECTION OF CHEMICALS

Table 9-1 shows the phases of treatment in which chemicals listed in Appendix 1 are used. In selecting a particular chemical for a certain phase of treatment the operator must consider the Jar Test results and the facilities available at the plant. Some factors are:

1. In order to obtain good coagulation and efficient use of coagulants, it is important that the treatment be carried out at the correct or optimum pH. In the case of alum, this will be within the range of pH 5.8 - 7.5, though normally within 5.9 - 6.3 sometimes less.

2. The most desirable pH at which coagulation with alum should be carried out, using the "Jar Test" techniques, followed by laboratory filtration, is usually around 6.0. Aluminium hydroxide is soluble in both acids and alkalies, and if the pH is not correct there will be excess aluminium in solution in the final treated water.

3. If the water being treated has a high pH and high alkalinity, the required alum dose will not destroy sufficient alkalinity to appreciably reduce the pH. Acid may have to be dosed in addition, to bring the pH to within the optimum range.

4. On the other hand, if the water has a low alkalinity and low pH, alkali in the form of sodium bicarbonate, sodium carbonate or lime must be added to prevent the pH from being depressed too far by the effect of the required alum dose. In either case, it is important that the sequence of addition is correct, and that the first chemical added, is mixed and uniformly distributed to the raw water before the

second is added. In the case of coagulation at low pH, it is normal to add the acid or alkali before the coagulant, although under certain conditions it may be reversed. These latter cases are unusual and are determined during jar-testing.

5. Waters of low alkalinity and also low free carbon dioxide, are unbuffered, and the addition of lime (Calcium Hydroxide) would produce a rapid increase in pH. Under these conditions it may not be possible in practice to accurately control the dose of lime to maintain the pH within the desired range. A weaker alkali such as sodium carbonate or even sodium bicarbonate, may have to be employed, although coagulation would be improved by using the calcium alkali.

6. Ferric salts and chlorinated ferrous sulphate will form floc at high pH (i.e. above 8.3) and at low pH (between 4.0 - 6.0). The high pH treatment is often employed when the water has a low colour, or where colour removal and organic matter removal is unimportant, since at this pH level, organic matter removal is poor unless high coagulant dosages are used.

7. High pH coagulation at above 8.3 requires neutralization of the dissolved carbon dioxide and this must be carried out by the addition of lime. Caustic soda or sodium carbonate cannot be used. The optimum pH may vary from 8.3-9.3 and depends mainly on the initial alkalinity of the water. If alkalinity is high, the optimum pH will be low, and if the alkalinity is low the optimum pH will be high. In this treatment, it is absolutely essential that the coagulant be added and thoroughly mixed and dispersed in the water at the correct concentration before the addition of the lime.

8. Iron salts can also be used for organic matter removal at the low pH range, but the pH of coagulation is critical in order to ensure low residual iron in the

treated water. Although there are some municipal waterworks installations (not in Canada) employing low pH coagulation with chlorinated ferrous sulphate on coloured water, a number of industrial installations using ferric sulphate or ferric chloride for organic matter removal, in this country there is very little practical published information on low pH coagulation with iron salts. Laboratory research indicates that all the iron salts do not produce similar results under otherwise identical conditions, and considerably more research into this form of treatment is planned.

9. Coagulant aids such as activated silica or polyelectrolytes are used for the purpose of increasing the efficiency of coagulation and producing tougher and more rapidly settling floc particles. The most well known of these is activated silica. Activated silica is produced by the addition of sulphuric acid, aluminium sulphate; ammonium sulphate, sodium bicarbonate, or chlorine to a solution of sodium silicate so that a silica "sol" is produced. Considerable care should be taken in adding exactly the right amount of activating agent to the sodium silicate.

10. Polyelectrolytes, coming under the general heading of "polymers" (cationic, anionic or nonionic) must always be dosed as extremely weak solutions and sometimes applied at several separate points to avoid areas of local high concentration. At present, it is not possible to predict which of the many polyelectrolytes will be effective under any set of conditions. The selection of the right material is still a matter of experiment on the plant. In general activated silica or polymers are not used unless satisfactory results cannot be obtained without them.

PHASES OF TREATMENT IN WHICH THESE VARIOUS CHEMICALS ARE USED

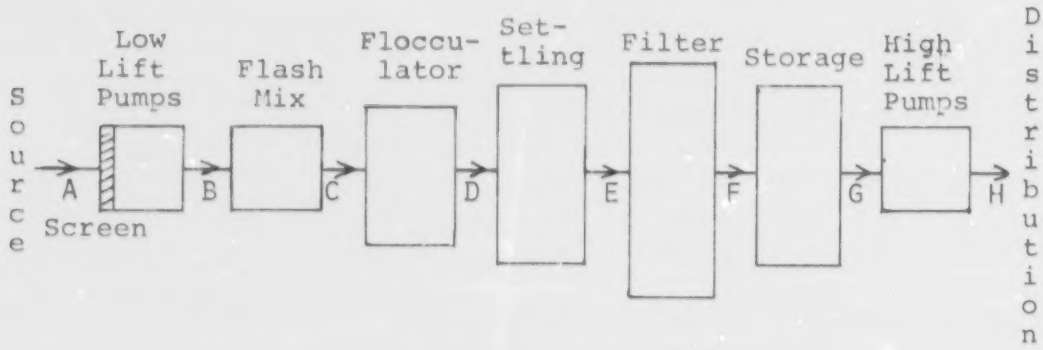
CHEMICALS	Coagulant or aid	Alkalinity & pH Adjustment	Disinfection	Dechlorination	Mineral Oxidation	Taste and Odour Control	Algae Control	Corrosion Control	Softening	Fluoridation
Activated Carbon				x		x				
Aluminum Sulphate	x									
Ammonia Anhydrous			x	x						
Ammonium Hydroxide			x	x						
Ammonium Sulphate	x		x							
Bentonite	x									
Calcium Hydroxide		x						x	x	
Carbon Dioxide		x							x	
Chlorine			x		x	x	x			
Chlorine Dioxide			x		x	x	x			
Copper Sulphate							x			
Ferric Chloride	x									
Ferric Sulphate	x									
Ferrous Sulphate	x									
Fluosilicic Acid										x
Hypochlorite, Calcium			x		x					
Hypochlorite, Sodium			x		x					
Ozone			x		x	x				
Pot. Permanganate					x	x				
Sodium Aluminate	x									
Sodium Bicarbonate		x								
Sodium Chlorite			x			x				
Sodium Fluoride										x
Sodium Hydroxide		x						x	x	
Sodium Silicate	x							x		
Sod. Silicofluoride										x
Sodium Sulphite				x						
Sodium Carbonate		x						x	x	
Sulphuric Acid		x							x	
Sulphur Dioxide				x						

The application points for chemicals related to a flow diagram are shown in Table 9-2.

TABLE 9-2 APPLICATION POINTS FOR CHEMICALS

CATEGORY OF CHEMICALS	POSSIBLE POINTS OF APPLICATION							
	A	B	C	D	E	F	G	H
Algicide	X				X			
Disinfectant		X	X		X	X	X	X
Taste and Odour	X	X	X		X	X		
Coagulants		X	X					
Coagulation Aids		X	X		X			
Alkali		X				X		
For flocculation			X					
For Corrosion control						X		
For softening			X					
Acidifier			X			X		
Fluorides						X		
Chloramine						X		
Dechlorinating						X		X

FLOW DIAGRAM OF WATER TREATMENT PLANT



With Solids - Contact Clarifiers, point C is same as point D.

EQUIPMENT

The different types of equipment being used for the feeding of chemicals in the form of gases, liquids or slurries, dry granular or powdered chemicals and unstable compounds, are numerous in design, and it is not possible to cover entirely this subject matter in the limited time allotted for this topic. However, to illustrate some of the equipment which is in use in Canada, the following is included:

1. Chlorinator

   Equipment of this type when used for chlorine, sulphur dioxide and ammonia, is called: a chlorinator, sulphonator and ammoniator. These dispensers can be used also for carbon dioxide and feature complete vacuum operation. The vacuum required for operation is produced by a water-powered ejector. The ejector discharge is a water solution of the gas being fed, permitting proper diffusion into the main body of water. Water to operate the ejector is obtained from the process or fresh water may be used. See Figure 9-1.

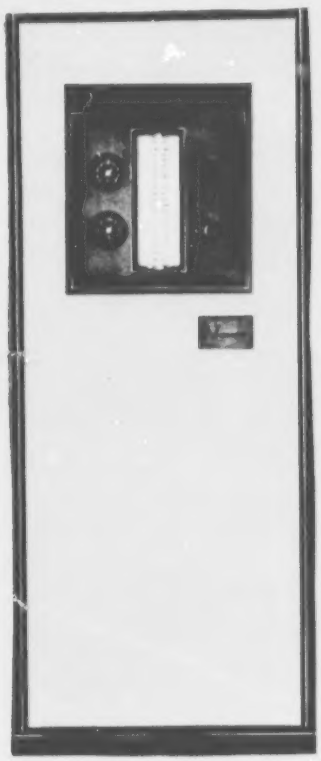


Figure 9-1
V - Notch Chlorinator
Courtesy, Wallace & Tiernan Inc.

2. Chlorine Dioxide Generator

This is a device for the continuous production of chlorine dioxide which is manufactured in the plant due to instability. By merging solutions of chlorine and sodium chlorite, chlorine dioxide is produced as the chemicals mix and flow through the generator.

The generator is a flanged glass chamber filled with porcelain Raschig rings. Separate inlet connections are provided for chlorine and sodium chlorite solutions at the base of the generator and an outlet connection for chlorine dioxide at the top. The generator is secured to a panel for easy well mounting. See Figure 9-2.

In operation, chlorine from a chlorinator is fed to one of the two inlets and a solution of sodium chlorite is fed by a diaphram pump to the other. The Raschig rings provide contact surface for the two chemicals as they mix and flow upwards. The glass generating chamber permits observation of the yellow colour produced by the presence of chlorine dioxide. See Figure 9-2a.

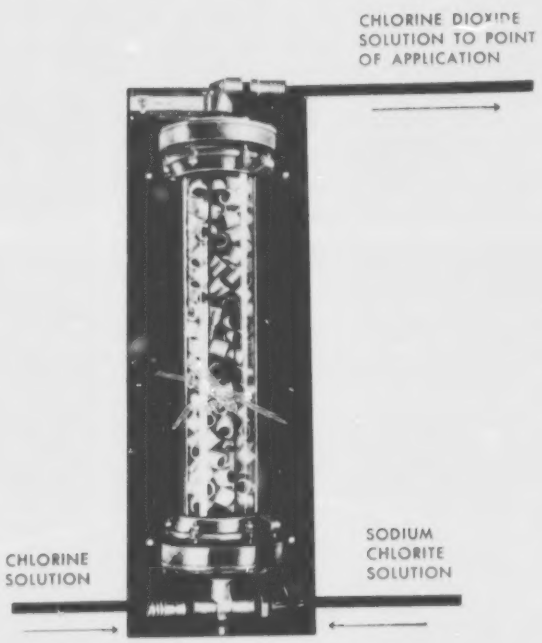


Figure 9-2

Chlorine Dioxide Generator

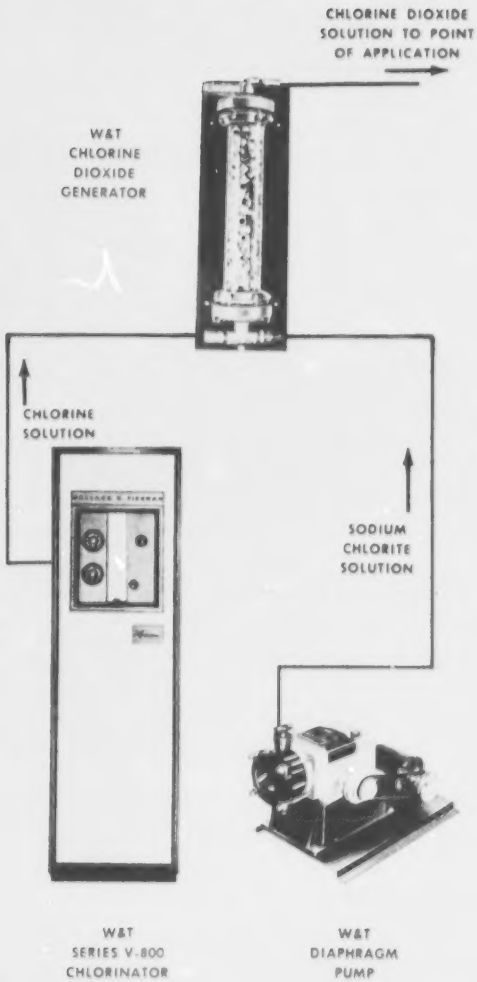


Figure 9-2a Chlorine Dioxide Generation System

3. Diaphragm or Metering Pump

This type of variable speed pump is suitable for the feeding of liquid chemicals or slurries. Both single and dual head models are available and include a 4 - step pulley for speed changes. A control knob adjusts stroke length and each head has its own indicating scale and control knob and by changing the belt on the 4 - step pulleys the discharge capacity of the pump is readily controlled. A flushing device is available also with the pump if required which is essential when feeding a slurry or a suspension. See Figures 9-3 to 9-5.

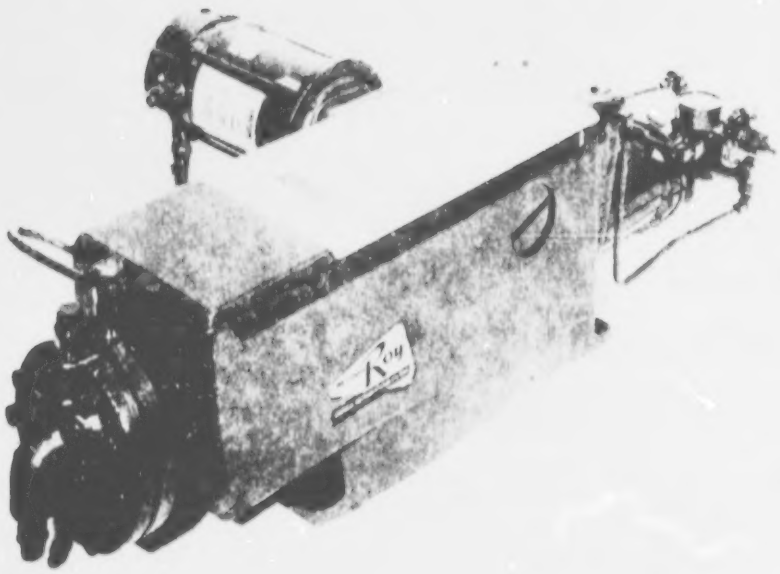


Figure 9-3 Diaphragm Pump Feeder (courtesy Milton Roy Co.)

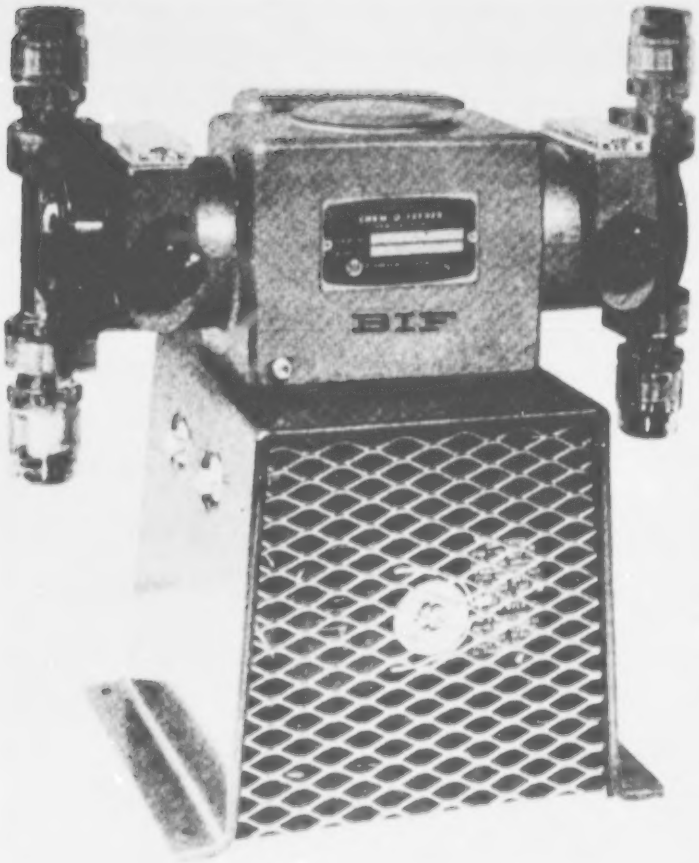
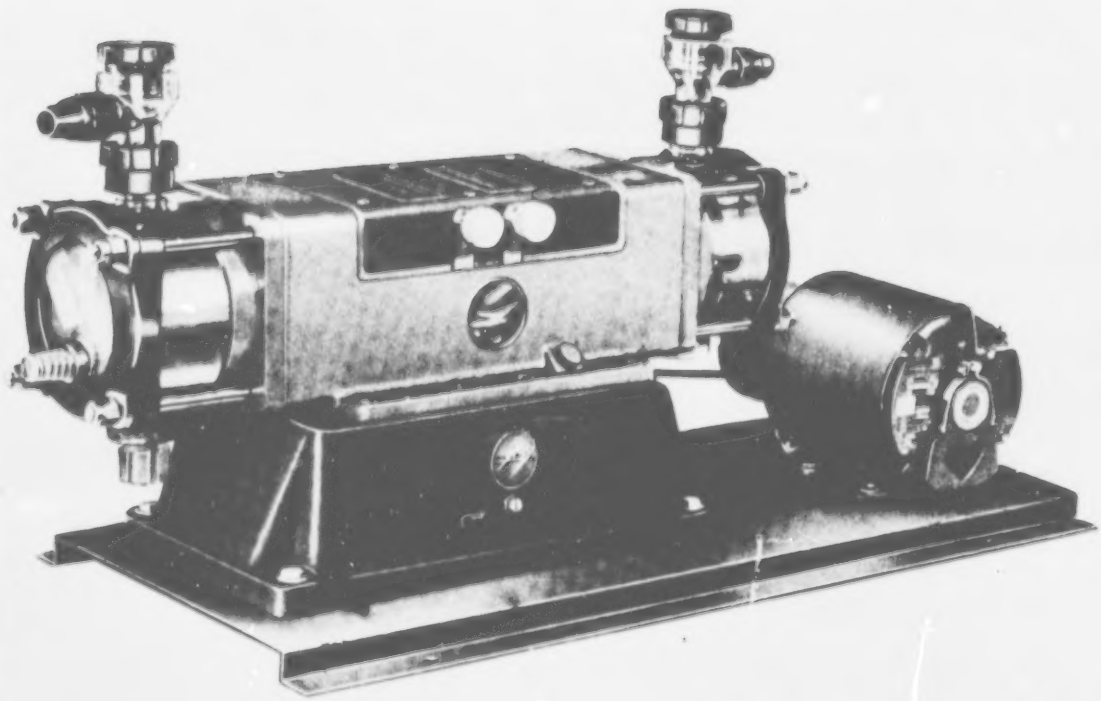


Figure 9-4
Chemical Solution
Feeder
Proportioneers
Courtesy
Omega Machine Co.

Figure 9-5
Chemical Solution
Feeder
Courtesy
Wallace & Tiernan



4. Rotodip Liquid Feeder

This type of feeder consists of a tank in which the chemical solution or slurry level is maintained by an over flow weir and a float valve, a dipper wheel with several dippers transfer predetermined quantities of liquid over a baffle to the discharge section and a variable speed drive to rotate the dipper wheel. Controls for adjusting the speed of the drive to rotate the dipper wheel may be manual or automatic. Delivery of the wheel may also be changed by changing the liquid level. A totalizer is necessary since the amount fed is calculated by the number of rotations multiplied by the dipper wheel delivery per rotation. See Figure 9-6.

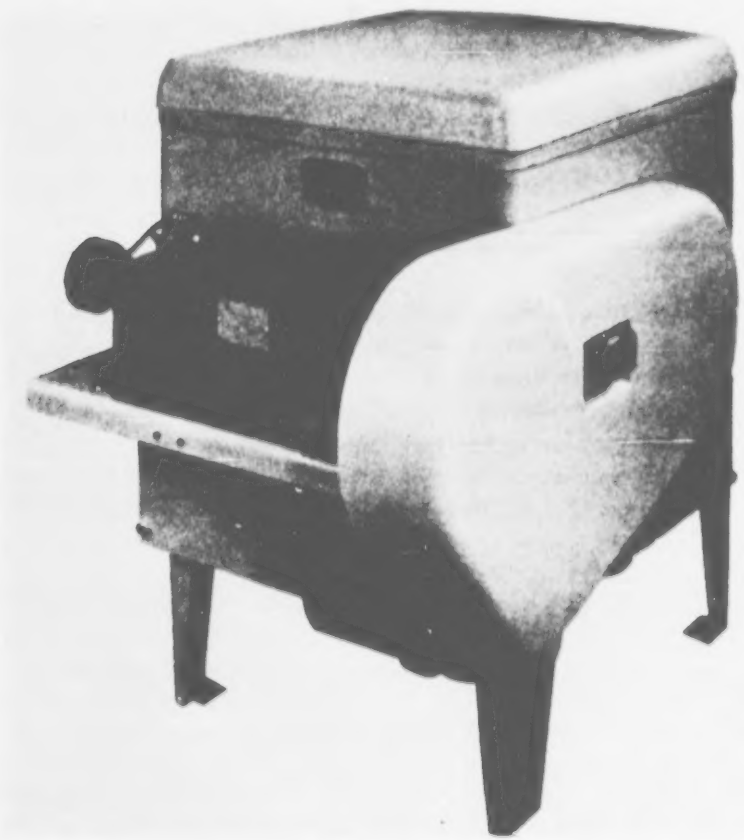


Figure 9-6 Rotodip Liquid Feeder (courtesy Omega Machine Co.)

5. Chemical Dry Feeder

Equipment of this type is used for feeding free flowing dry granular or powdered chemicals. All dry feeding requires use of solution or slurry tanks, and this is included as an integral part of this unit with the feed mechanism mounted on the top and dropping the chemical directly into it. See Figure 9-7.

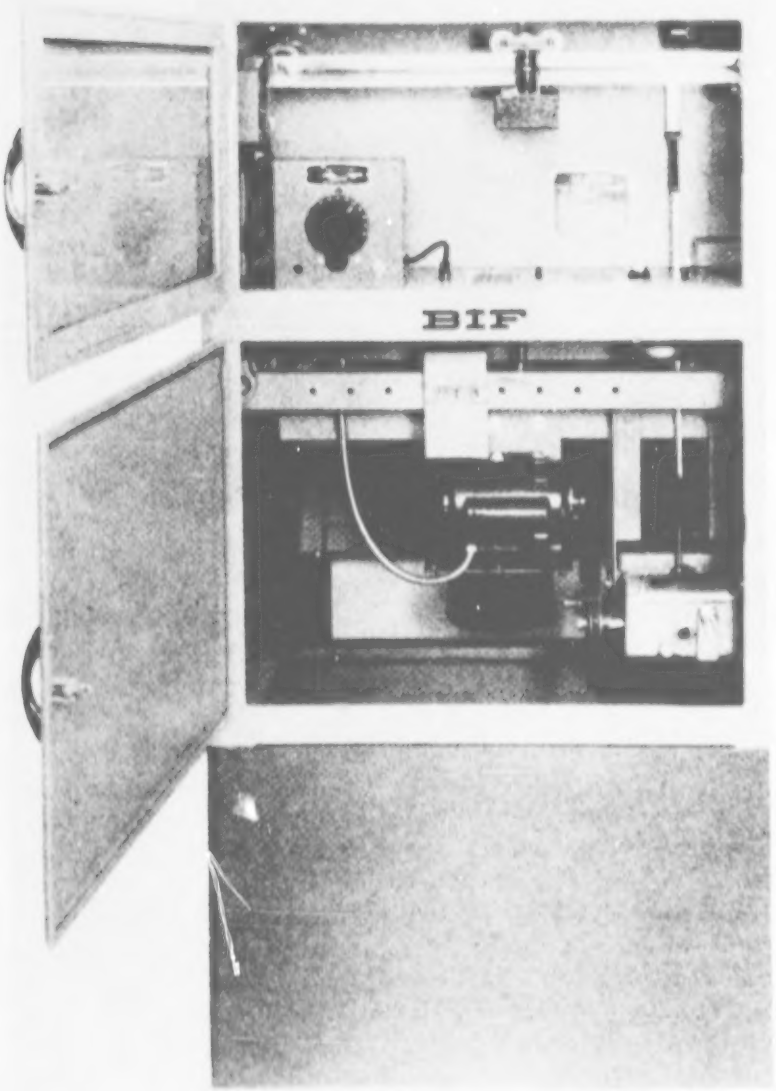


Figure 9-7 Dry Chemical Feeder (courtesy Omega Machine Co.)

CHEMICALS USED IN WATER TREATMENT

1. Activated carbon, (Carbon) Dry, black, powdered or granular, highly porous and adsorptive; C; 15 to 20 lbs. per cubic foot; insoluble; dust and flammable; 95 per cent C, phenol absorption value of 20 to 27.

2. Aluminum Sulphate. (Alum) 1. Dry, crystalline, white to grey, lump to powder, slightly hygroscopic; $Al_2(SO_4)_3 - X(H_2O)$; 60 to 75 lbs. per cubic foot; 9.4 lb per gallon at 32°F., 10.0 at 60°F.; irritating and astringent dust; 17 per cent soluble Al_2O_3 or 9 per cent soluble Al: 2. (Liquid), slightly brownish; $Al_2(SO_4)_3 \times H_2O$; 8.3 per cent Al_2O_3 weighs 13.4 lb. per gallon; crystallizes at 20.°F. with content of 8.46 per cent Al_2O_3; skin irritants; 8.3 per cent Al_2O_3 or 4.25 per cent Al equals 6.5 lbs dry alum per gallon. (N.B. 'X' in alum formula can vary between 7 and 18. It denotes water of crystalization.)

3. Ammonia, Anhydrous. (Ammonia) Gas, colourless, compresses to liquid, pungent odour; NH_3; 38.5 lb per cubic foot of liquid at 60°F; 3.7 lb. per gallon soluble at 60°F.; respiratory irritant, explosive in air at concentrations of 16 to 25 per cent; 99 per cent NH_3.

4. Ammonium Hydroxide (Aqua Ammonia) Liquid, colourless, must be contained at below 80°F.; NH_4OH; 9 lb. per gallon weight at 29.4 per cent NH_3; solubility 29.4 percent NH_3 irritating fumes; 29.4 to 10 per cent NH_3.

5. Ammonium Sulphate. (Sulphate of Ammonia) Dry, grey to brown crystals to fine granules, hygroscopic and cakes; $(NH_4)_2 \cdot SO_4$; 60 lb. per cubic foot; 7 to 8 lbs. per gallon soluble; some irritating fumes and dries skin; min. 99.5 per cent $(NH_4)_2SO_4$ or 25 per cent NH_3.

6. Bentonite. Dry, pellets to powder, forming a colloidal solution in water; $(Al_2O_3.Fe_2O_3MgO)\ 4SiO_2.\ NH_2O$; ('N' refers to the number of molecules of water of crystallization) 60 lb. per cubic foot; insoluble; dust; a colloidal clay.

7. Calcium Hydroxide. (Hydrated lime, slaked lime, calcium hydrate) Dry, 200 to 400 mesh white powder, high angle of repose but when aerated flows like liquid, alkaline, very slightly hygroscopic; $Ca(OH)_2$; 35 to 50 lb. per cubic foot; solubility less than 0.2 lb. per gallon; dusty and burns skin; "high calcium", 86 to 96 per cent $Ca(OH)_2$, "dolomitic" less Ca but up to 30 per cent $Mg(OH)_2$.

8. Carbon Dioxide. (Carbonic acid gas) Gas, compresses to liquid, colourless, odourless, non-combustible and non-corrosive (also white, solid "dry ice"); CO_2; liquid 68.8 lb. and solid 97.5 lb. per cubic foot; solubility 0.36 lb. per gallon at 32^oF. and 0.18 lb. per gallon at 68^oF.; respiratory hazard; 100 per cent CO_2.

9. Chlorine. (Liquid Chlorine, Chlorine Gas) Gas, greenish-yellow, very pungent, non-corrosive when dry but very corrosive when wet, 463.4 volumes of gas compresses to 1 volume of greenish-yellow liquid; Cl_2; gas at 32^oF and 1 atmosphere = 0.198 lb. per cubic foot, liquid at 32^oF = 91.7 and at 68^oF = 88.0 lb. per cubic foot, at 50^oF. solubility = 0.096 lb. per gallon; strong respiratory irritant, also poisonous; 99.8 per cent Cl_2.

10. Chlorine Dioxide. Gas, green-yellow, or when cooled becomes red liquid; ClO_2; 2.4 times the weight of air; solubility exceeds 0.1 per cent by weight; strong respiratory irritant, also poisonous; manufactured in plant due to instability.

11. Copper Sulphate. (Blue Vitriol, bluestone) Dry, blue crystals to snow, nonhygroscopic; $CuSO_4.5H_2O$; 75 to 93 lb. per cubic foot; solubility at 32° F = 1.92 and at 86° F. = 3.12 lb. per gallon; dust and also toxic; 99 per cent $CuSO_4.5H_2O$ or 25.2 per cent Cu.

12. Ferric Chloride. 1. Anhydrous is reddish-brown crystal, deliquescent and very corrosive; $FeCl_3$; 85 to 90 lb. per cubic foot; solubility unlimited; hazardous internally and will destroy shoes and clothing; 98 per cent $FeCl_3$ (34 per cent Fe^{+++}): 2. Crystals are deliquescent; $FeCl_3.6H_2O$; 60 to 64 lb. per cubic foot; 59 to 61 per cent $FeCl_3$ (20 to 21 per cent Fe^{+++}): 3. Liquid, at 60°F., 34 per cent $FeCl_3$ (11.6 per cent Fe^{+++}) weighs 12.9 lb. per gallon and 46 per cent $FeCl_3$ (15.7 per cent Fe^{+++}) weighs 14.4 lb. per gallon.

13. Ferric Sulphate. Dry, granular, reddish grey, free flowing, mildly hygroscopic, quite corrosive; $Fe_2(SO_4)_3.9H_2O$; 70 to 75 lb. per cubic foot; solubility 1 part in 1 part (50 per cent); dust, hazardous internally, will ruin shoes, 18 to 22 per cent ferric iron (Fe^{+++}).

14. Ferrous Sulphate. (Coppers, iron sulphate, sugar sulphate, green vitriol) Dry, green crystals which cake, very hygroscopic; $FeSO_4.7H_2O$; 65 to 70 lb. per cubic foot; solubility 2.4 lb. per gallon at 70°F; no special hazard; 55 per cent $FeSO_4$ (20 per cent Fe^{+++}).

15. Fluosilicic Acid. (Liquid Fluoride) Liquid, colourless to straw, quite stable, no appreciable viscosity; H_2SiF_6; 24 per cent = 12.159, 28 per cent = 12.56, 32 per cent = 12.975, 36 per cent = 13.379 per gallon; soluble in all proportions; vapours corrosive and respiratory hazard, slow irritant to skin; 24 to 36 per cent H_2SiF_6 = 19 to 28.6 per cent F.

16. Hypochlorite, Calcium. (HTH, Perchloron, Pittchlor) Dry, granular to powder or tablets, white to yellowish, hygroscopic; $Ca(ClO)_2.4H_2O$; 52.5 lb. per cubic foot; soluble to 3 per cent available chlorine; fumes poisonous and irritating to the skin; 70 per cent available Cl_2.

17. Hypochlorite, Sodium. (Chlorine bleach, bleach liquor) Liquid, light yellow, strongly alkaline, very active, NaOCl; 11.76 to 12.0 lb. per gallon; soluble in all proportions; slight fumes are irritating; flammable with materials such as oil, grease, paper, glycerine; 12 to 18 per cent available Cl_2.

18. Ozone. Gas, colourless, sweetish odour, very strong oxidant; O_3; 1.658 times the weight of air, soluble to 0.5 per cent by weight; inhalation must be limited; manufactured at the water plant due to instability.

19. Potassium Permanganate. Dry, purple, solid granules, hygroscopic, powerful oxidant; $KMnO_4$; 90 lb. per cubic foot; solubility at 32°F. = 0.3 and at 68°F = 0.6 lb. per gallon; poisonous, dust, also fumes from solution; 97 to 99 per cent $KMnO_4$.

20. Sodium Aluminate. (Soda Alum) 1. Dry, white to greyish, crystals, odourless, slightly hygroscopic; $NaAlO_2$; 45 to 60 lb. per cubic foot; soluble to 3.6 lb. per gallon at 68°F., (contains 6 to 8 per cent insolubles); strong alkali causes skin burns; 46 to 55 per cent Al_2O_3 + 31 to 35 per cent Na_2O + 5 per cent NaOH: 2. Liquid, nearly colourless; at 27° Be = 32 per cent $Al_2O_3.Na_2O$ + 9 per cent NaOH.

21. Sodium Bicarbonate. (Sodium Hydrogen Carbonate or Baking Soda) Dry; white powder; free flowing; odourless: slightly hygroscopic; $NaHCO_3$ - 130 - 138 lb. per cubic foot. Solubility at 32°F = 0.69 lb per gallon and at 140°F = 1.64 lb. per gallon; dusty no special hazard; 99 to 100 per cent $NaHCO_3$.

22. Sodium Carbonate. (Soda Ash) Dry, White powder, free flowing, slightly hygroscopic; Na_2CO_3; extra light, light and dense grades = 23, 35 and 65 lb. per cubic foot; at 32, 50 and 68°F. solubility is 0.7, 1.0 and 1.8 lb. per gallon; dust hazard, and solution is caustic; 99 per cent Na_2CO_3 or 58 per cent Na_2O.

23. Sodium Chlorite. 1. Dry, White to orange, flake or powder, slightly hygroscopic, powerful oxidant; $NaClO_2$; 50 lb. per cubic foot; at 41°, 63° and 68°F. solubility is 3.36, 3.84, and 4.56 lb. per gallon; fire hazard when dry on clothing or with organic matter or sulphur, may react violently with spark, heat, pressure or scraping; 78 to 85 per cent $NaClO_2$: 2. Liquid, tan to brown, slightly viscous; 40 per cent $NaClO_2$ weighs 14 lb. per gallon; 38 to 42 per cent $NaClO_2$.

24. Sodium Fluoride. (Fluoride) Dry, white crystals or powder, free flowing, slightly hygroscopic, sometimes artificially coloured blue; NaF; powdered 60 to 75 lb. per cubic foot and crystals 75 to 90; soluble to 0.42 lb. per gallon; dust hazard, and poison internally; 97 per cent NaF= 43 per cent F.

25. Sodium Hydroxide. (Caustic soda, soda lye) 1. Moist, white, crystalline, flakes to powder, quite hygroscopic; NaOH; weight varies; solubility at 32° and 68°F. is 2.88 and 5.28 lb. per gallon; causes serious skins burns, slight fumes respiratory hazard; 98.9 per cent NaOH equals 76.5 per cent Na_2O: 2. Liquid, 50 per cent solution weighs 15.24 lb. per gallon; 59 to 73 per cent NaOH available.

26. Sodium Silicate. (Water glass) Liquid, opaque, syrupy, alkaline solution; $2Na_2O.XSiO_2+H_2O$, with X varying from 1 to 7.5; weight varies; solubility 20 to 55 per cent; non-hazardous; various formulae available.

27. Sodium Silicofluoride. (Sodium fluosilicate) Dry, powder, white to yellow or artificial blue, free flowing, odourless; Na_2SiF_6; 75 to 95 lb. per cubic foot; at 35° and 75°F. solubility is 0.43 and 0.75 per cent; dust hazard and poisonous; 98.5 per cent Na_2SiF_6 = 59.7 per cent F.

28. Sodium Sulphite. (Sulphite) Dry, white, crystals or powder; Na_2SO_3; 80 to 91 lb. per cubic foot; solubility from 1.2 to 2.4 lb. per gallon; non-hazardous; 93 to 98 per cent Na_2SO_3.

29. Sulphuric Acid. (Vitriol, oil of Vitriol) Liquid, nearly colourless, very corrosive when diluted; H_2SO_4; 66° and 60° Be weight 18.36 and 17.16 lb. per gallon; completely soluble; will destroy flesh, ignite with organic matter, explosive when mixing with water; 66° and 60° Be = 93.2 and 77.7 per cent H_2SO_4.

30. Sulphur Dioxide. Gas, colourless, noncorrosive when dry, very corrosive when wet, pungent odour; SO_2; gas weight is 2.264 times the weight of air (liquid at 68°F. = 89.6 lb. per cubic foot); solubility at 32° and 68°F. is 1.2 and 2.4 lb. per gallon; liquid burns skin, gas or liquid hazardous to eyes and internally; 99.9 per cent SO_2.

SUBJECT:

WATER TREATMENT OPERATIONS

TOPIC: 10

Safety

OBJECTIVES:

The trainee will be able to:

1. Name three (personal) hazards common to treatment plants;
2. Recall the safety rules to follow when working in or around -
   a) Wet Wells
   b) Chlorine Rooms
   c) The Laboratory;
3. List at least eleven precautions to take for electrical maintenance;
4. Recall eight rules to follow to prevent body infection;
5. Recall ten general safety practices to be followed when working in the plant.

SAFETY PRACTICES IN TREATMENT PLANTS

INTRODUCTION

The dangers associated with plant operations emphasize the need for safety practices. Physical injuries and body infections are a continuous threat and occur with regularity. Explosions and asphyxiations from gases or oxygen deficiency occur. Although infrequent at any particular location, country-wide such accidents are a daily happening. These occupational hazards may be largely avoided by the execution of safe practices and the use of safety equipment. The dangers are many and carelessness all too frequently prevails until an accident results. Then it is too late.

It is the responsibility of supervisors to acquaint themselves with the hazards associated with plant maintenance and operation and to take steps to avoid them. Accident prevention is the result of thoughtfulness and the application of a few basic principles and knowledge of the hazards involved. It has been said that the "A,B,C," of accident prevention is "Always Be Careful". One must learn how to be careful and what to avoid. With this knowledge one can then always think and practise safety.

HAZARDS

The overall dangers of accidents are much the same whether in manholes, pumping stations or treatment plants. These result from:

1. Body infections
2. Physical injuries
3. Dangerous noxious gases or vapours, oxygen deficiencies and hazardous chemicals.

BODY INFECTION

Workers in treatment plants are exposed to the hazards of water-borne diseases, including Typhoid Fever, Amoebic Dysentery, Infectious Jaundice and other intestinal infections. Tetanus and skin infections must also be guarded against.

A majority of infections reach the body by way of the mouth, nose, eyes and ears. Therefore, washing your hands is a must before eating or smoking. Wear protection gloves where possible.

Soap preparations requiring no water rinse are available for field use. The common drinking cup should be banned, each man should have and use his own.

Typhoid and Tetanus innoculations are recommended. These may be obtained free of charge from local Health Officers.

This hazard to plant personnel although very real and ever present can be largely reduced by the operator himself by following a few basic rules of personal hygiene. A few of these self applied rules are as follows:

1. Never eat your lunch or put anything into your mouth without first washing your hands.
2. Refrain from smoking while working in open tanks, on pumps, or cleaning out grit channels, etc. Remember you inhale or ingest the filth that collects on the cigarette from dirty hands. Save your smoking time for lunch hours or at home.
3. A good policy is "never put your hands above your collar when working on plant equipment".
4. Rubber or rubberized cotton gloves, rubber boots and coveralls are designed for body protection against dampness and contact with dirt, wear them at all times when working in tanks, etc.

5. Rubberized or rain suits can be worn in very wet or dirty places and can be washed off with a hose and brush, the same as rubber boots.

6. Always wear your rubber boots when working in tanks, washing down etc., don't wear your strect shoes.

7. Don't wear your rubber boots or coveralls in your car or at home.

8. Always wear rubber or plastic coated gloves when cleaning out pumps, handling hoses, etc.

9. Don't just wash your hands before going home, wash your face too, there is as much of your face to carry germs as there is of your hands.

10. Wear a hat when working around sludge tanks, cleaning out grit and other channels, don't go home with your head resembling a mop that just wiped up the floor around a cleaned out pump.

11. Keep your finger nails cut short and clean, they are excellent carrying places for dirt and germs.

PHYSICAL INJURIES - First Aid

Except for minor injuries, wounds should be treated by a doctor and reported for possible Workman's Compensation. Service truck and plants must have first aid kits. It is recommended that all plant personnel should receive "St. John Ambulance" first aid instruction.

It is a "Compensation Board" regulation that any plant having five (5) or more people working as a group on any shift, one of them is required to hold a "St. John Ambulance Certificate" in first aid. Remember, no cut or scratch is too minor to receive attention.

HAZARDOUS MATERIALS

The dangers of hazardous material are dealt with later in this topic.

THE PLANT SAFETY PROGRAM

Before starting a safety program, the full co-operation and active support of management is needed. One person in the utility organization must be responsible for the program. In a small water works system, that person may be the superintendent, while in a larger organization, another person who can devote part or full time to the job can be appointed.

The next step in setting up the program is to provide for:

1. Keeping injury records
2. Identification and location of the hazards
3. Making equipment, plant arrangements and working methods safe
4. Getting employees interested in safety
5. Controlling work habits

Injury Records

The keeping of injury records is basic to a safety program. With complete records, the program is given direction and is sure of success. The records should be kept brief but must contain all pertinent data. The forms should cover such items as:

1. Accident report
2. Description of accident
3. Physician's statement
4. Corrective action taken
5. Accident analysis chart

Locating the Hazards

The person responsible for the safety program should be constantly on the alert for hazards which may cause an injury to an employee. One of the best methods of attacking this problem is to search the records for the conditions and situations that have produced injuries. Records like this show the need for a corrective program.

Many other sources of information on hazardous conditions are available. These include safety manuals, insurance company brochures, etc. They should be used freely and frequently.

Equipment, Plant Arrangements, Working Methods

Nothing prevents an accident as effectively as the elimination of the cause. To preach safety while permitting unsafe conditions will discourage the cooperation required from employees. Only when safety is integrated with the job are workers convinced that the man responsible for safety wants to prevent accidents.

Some Protective Safety Equipment

The need for protective safety equipment in an accident prevention program has proven its value many times; the program cannot be successful if any phase of accident prevention is overlooked.

Use safety equipment as it was meant to be used. This should be compulsory during the performance of hazardous jobs.

Protect eyes and face when there is any possibility of injuries from hand tools, power tools, welding equipment, etc.

Protect feet with safety shoes to safeguard against injuries while breaking pavements, tamping trenches, handling materials, etc.

Protect head (with hard hats) to prevent serious injuries in construction, excavation or electrical work.

Protect hands (with gloves) to prevent injuries from occurring when handling materials, sharp objects, chemicals or electrical equipment.

Use air packs when hazards such as chlorine, painting or dusty areas exist.

Prevent accidents due to falls by using safety belts, scaffolds, etc.

GENERAL PLANT SAFETY

When working at the plant, observe the following common sense rules:

Keep walkways clear of loose objects such as pails, shovels, loose rope, etc.

Wipe up grease and oil *immediately;* salt or sand icy walks.

Pick up all tools, clean them and return them to their storage area.

When it is necessary to use tools in an empty tank or manhole, etc., lower them in a pail on a rope and remove them in the same way. Brooms and shovels can also be transported by rope. *Do not attempt to climb up and down ladders with your hands full of tools.*

Do not overload yourself when using stairways. Keep your load small enough to be able to see over it. Always keep one hand free to use the hand-rail.

Do not try to climb up or down a ladder or over a railing when handling a hose under pressure.

Always wear hip wader rubber boots with good treaded soles when washing down the floor of any tank. *Do not* wear rubber boots with worn soles and heels.

Always wear the rubber clothing provided when working in a narrow or confined passage where grit or sludge accumulates.

Always wear rubber or plastic coated, waterproof gloves when cleaning pumps, handling hoses, removing grit or sludge, etc.

When it is necessary to use an extension ladder to enter any empty tank, use the collector arms in the clarifiers to backstop the ladder legs. In an aeration tank, lash the ladder. Enter the tank from a walkway (not from a narrow dividing wall) and *always lash the ladder to a hand-rail.*

Always wear hard hats when working below ground level (in tanks, manholes, etc.) or under scaffolding.

Do not hang clothes on electrical disconnect handles, light switches or control panel knobs.

Replace all manhole covers and trap doors to wells. Close after using. If it is necessary to leave them open, *protect them with guard-rails.*

Use the proper tool when removing or replacing manhole covers. *Do not* attempt to move or close a manhold cover with your hands.

When working in manholes located in a street or road, post signs with blinking amber lights and red flags at each approach to the area.

Do not pull up grit-filled pails by rope when removing from tanks or wet wells. Use an "A" frame and pulley or some other type of support with a pulley. Be sure the support and pulley are fastened firmly to prevent them from toppling over during use.

Always wear a safety belt with a short rope and a safety snap when leaning out through the railings over any tank (or cleaning out spray nozzles, etc.)

Be very careful during repair work on fuel systems of gasoline engines. *Close the shutoff valve* from the tank and *be sure there is adequate ventilation* while draining the fuel system.

Check the ventilation of any enclosed or underground areas when gasoline operated pumps are to be used.

Do not refill a gas engine when in operation or while still hot. *Remove* spark plug from engine before cleaning out pump unit.

Building Maintenance

Periodic inspections are necessary to eliminate hazards (fire safeguards, etc.). Suggested repairs for safety should receive immediate attention. Floors, hallways, and stairways should always be well lighted, clean, orderly and free from oil, dirt and debris. Immediate repairs of hazardous electrical outlets and fixtures should be routine. Adequate sanitary facilities for employees must be provided. Hand-rails on steps and stairways should always be provided and used. *Good housekeeping must be maintained.*

Hand Tools

Hand tools are the cause of many accidents and injuries when improperly used and in unsafe condition. Therefore, use the right tool for the right job in the right way. Use protective safety equipment where there is a job hazard. Keep the work area clear of hazards, with plenty of working space for solid footing. Tools should be in good condition and used for the purpose for which they were intended.

Portable and Power Tools

All equipment should be grounded. Check wiring and equipment regularly for defects. Be very careful when using equipment in wet areas. Use protective safety equipment when operating grinders, buffers, or other tools when there is danger of flying material.

Tools and Machines

Use protective equipment when operating power equipment if there is any chance of flying objects or other injuries. Inspect all tools and equipment for safe operation. Necessary repairs or replacements should be made immediately. *Repair power tools and machinery only when the equipment is turned off.*

Welding

Use the proper protective equipment at all times. Check for fire hazards before cutting or welding in areas of inflammable or explosive mixtures. *Only authorized personnel should operate welding equipment. The Ministry of Labour requires a 2 3/4 lb fire extinguisher be fastened to the welding truck.*

Inspections of Tools and Equipment

Periodic inspections should be made of tools and equipment so that those that are broken or worn out may be replaced. *Report worn or broken equipment* and be sure they are replaced or repaired as soon as possible.

Ladders

Ladders should be inspected periodically and maintained in good order. *Use safety belts* when awkward positions are necessary for the work. *Do not use metal ladders for electrical work.*

Lifting

Always lift with the leg muscles instead of the back and be sure your footing is secure. Bend your knees and keep your back straight. Don't turn or twist your body when lifting. Get help if load is too heavy or awkward to handle. Use mechanical device for lifting wherever possible.

Sanitation

Washrooms, toilets, locker rooms, drinking fountains and showers that are clean, ventilated and adequately built are good for employee morale. Clean drinking water and paper cups should be available at each plant, especially if the employees are exposed to skin irritant materials.

Storerooms

Good housekeeping must be maintained at all times. Space should be well arranged to permit proper storage, handling and movement of materials. Inspections should be made regularly for fire hazards. Fire extinguishers should be in good order and easily accessible.

Working Area

A safe working area must be provided for efficient work. In the filed, traffic should be controlled by the use of traffic cones, barricades, flags, etc., to protect the workmen as well as the public. In the material yard and storerooms, good housekeeping and properly planned storage and work areas must be provided for safe working practices. Shops, plants and offices should be planned for the most efficient production.

Trucks and Equipment

Routine inspections of trucks and equipment should be made. Any need for repairs should be reported and acted on as soon as possible. Only qualified and licensed operators should be permitted to use and operate vehicles and equipment. Never permit riders on trucks or other mobile equipment. Check electrical and any other hazards constantly when moving heavy equipment. All trucks should be equipped with first aid kits, fire extinguishers, and flares.

Barricades and Traffic Control

An adequate and safe work area must be protected. Sufficient traffic cones and barricades should always be carried by crews assigned to construction or maintenance work in streets. Paint barricades bright, visible colours and keep them in good condition. Be sure warning signs, flags, flares are adequate and in positions where they can be easily seen.

EQUIPMENT SERVICING

When servicing plant and equipment, Do Not:

1. Grease or oil or attempt to service any machinery while it is in operation. Pumps on automatic control must be locked out and key carried by the operator during servicing.
2. Make any adjustments to operating machinery while alone. If it is necessary to run the unit to adjust it, a second man must be present and be beside the stop and go switch.
3. Work around electrical panels, disconnects or switches alone.
4. Enter any crawl space under flooring for any purpose until the area has been ventilated. A second man should be present.
5. Service pumps and shafts in the dry wells of pumping stations, and in plants where the pumps and shafts are less than three feet apart, without shutting off all pumps and locking them out.
6. Under any circumstances, attempt to grease or service pump shafting while standing on beams, piping, loose planks, guard rails, or by leaning out, over or through guard rails. If a ladder must be used, then a second man must be present to hold the ladder steady and to provide any other assistance.

PRECAUTIONS FOR ELECTRICAL MAINTENANCE

1. Plan safety into each job. Orderliness and good housekeeping are essential for your safety and the safety of others.
2. Each employee shall be qualified both in experience and general knowledge to perform the particular electrical work which he is assigned. Outside contractor to be called in.
3. Study the job carefully to determine all of the hazards present and to see that all necessary safeguards and safety devices are provided for safe working conditions.
4. Examine all safety devices before they are used to ensure that they are in good condition.
5. In all cases where work is being performed on or close to live conductors or equipment, at least two men shall work together. When it is necessary for one to leave, the other workman shall not continue the work until the first man returns.
6. Consider the results of each action. There is no reason for you to take chances that will endanger yourself and others.
7. Satisfy yourself you are working under safe conditions. The care exercised by others can not be relied upon.
8. Wear close fitting clothing, keep sleeves rolled down, avoid wearing unnecessary articles while working on or close to live circuits or apparatus.
9. Use only approved types of rubber or leather gloves.
10. Protect yourself by placing an insulated medium between you and ground or grounded apparatus to keep any part of your body from providing a path for electrical current when working on conductors or apparatus that may be energized.

11. Use rubber mats when working on any electrical control panel or switch and disconnect boxes.

12. Open and close switches completely with a firm positive motion. Switches in a partly open position may arc or cause a flash-over with damaging results to the switch and possible injuries to the operator.

13. Open switches fully before removing fuses. To remove a fuse from a circuit carrying a current without opening the switch is particularly hazardous. Use an approved low-voltage fuse puller to remove fuses on a circuit of less than 500 volts (where no switch is provided) whether a disconnect is provided or not. Remove fuses by breaking contact with the hot side of the circuit first. Use the reverse procedure when replacing fuses. Insert the fuse in the cold terminal first.

14. Do not stand directly in front of panel to remove fuses or shut off disconnects.

15. Shut off the power when examining or making repairs or alterations on light and power circuits. When this is impractical Head Office must be contacted for further instructions before proceeding with the work.

16. Consider all electrical circuits to be dangerous. Treat dead circuits as though they were alive. This may prevent an accident as the circuit may be closed through an error of some other person.

17. Exercise extreme care when required to locate troubles on a series lamp circuit, before repairs are made make sure the power is cut off.

18. Lock or block open the control devices, open disconnect switches or remove fuses before examining, repairing or working on power circuits. After

these precautions have been taken, attach tie-up tags worded "WORKMEN ARE WORKING ON LINE." The tag shall bear the name of the workman. Tie-up tags shall remain on the opened devices until removed by the workman whose name appears on the tag. If the workman leaves without removing his tag, it may be removed only on authorization of Head Office.

19. Before working on line circuits at a point remote from the control switch, which has been tagged, it is recommended that the conductors be grounded at a point on the line between the switch and the work station.

20. Make a complete check of the circuit before applying power for the first time. This is to be done by a qualified man in charge of the repairs, all other workmen to stand off at a safe distance.

FIRE PROTECTION

Good housekeeping is the basis for fire prevention. Inspections should be made periodically and correction of fire hazards should be made as soon as possible. Consult local fire departments for recommendations.

Each operator should have first hand knowledge of fire extinguisher, its ABC rating point of contact and time of operation.

A CO_2 fire extinguisher can only be used in an open area where the chance of using up the local oxygen is minimal. Never grab the horn of the extinguisher to direct the CO_2. The gas being expelled will freeze your hand to the horn causing serious injury. There is a handle provided. Do not direct the CO_2 at anyone. To fight the fire you must approach the fire from upwind, pull the pin and aim directly on the burning area.

The approximate operating time for CO_2 fire extinguishers is as follows:

2½ lb. 10 sec. ± 2 sec. 2. BC.
5 lb. 14 sec. ± 2 sec. 4. BC.
10 lb. 14 sec. ± 3 sec. 6. BC.
15 lb. 25 sec. ± 4 sec. 8. BC.
20 lb. 30 sec. ± 4 sec. 8. BC.

Note: The 2. BC etc., refers to the type of fires and area the extinguisher covers. (BC) indicates electrical, gas, oil type fires, "A" type are wood, paper, etc., CO_2 will not be effective on "A" type fires.

(2) indicates the extinguisher will put out a fire of not more than 2 square feet in area.

Weight indicated refers to contents only.

A Dry Chemical extinguisher can be used in any area. Approach from upwind and pull the pin, you do not have to stand as close to the fire as with CO_2. Dry Chemical will put a blanket of chemical over the fire, smothering it.

Note:

1. *All extinguishers must be refilled after using no matter what amount has been used.*
2. *All extinguishers must be hydrostatically tested every five years.*

CHEMICAL HANDLING AND STORAGE

The Industrial Safety Act, Ministry of Labour, states that the employer is responsibile for providing the necessary protective equipment and clothing for handling dangerous materials. It is the responsibility of the employee, both to his employer and to himself, to use and maintain them.

Eyewash fountains and deluge showers must be located within fifteen (15) feet of the entrance to any chemical handling area. Plenty of water should be available for washing up after handling chemicals. Protective clothing should be washed after use.

All areas where solvents or other compounds are used and stored must be well ventilated. The working area must be designed and constructed for the safety and convenience of the worker and for his efficient production. The ventilation should be by mechanical means *with the air intake drawing air from the outside*. In rooms where lime and other dry types of chemicals are used, install dust accumulators in the air discharge pipe.

Operate exhaust fans when handling any chemical whether liquid or dry.

Wear rubber boots, apron, gloves and eye shield or goggles when handling liquids. Wear nose and mouth filter masks and goggles when handling dry chemicals.

LABORATORY

1. A thorough knowledge of first aid for dealing with lab accidents is essential. Know the relevant sections of the antidote chart.
2. Wear protective clothing.
3. Practise good housekeeping. Keep all unnecessary equipment out of working areas. *Use a separate marked container for broken glass.*
4. Areas around sinks and taps should be kept clear so that chemicals spilled on one's hands or person can be washed off quickly.
5. Wipe up all spills immediately.
6. All reagent bottles must be clearly labelled so they can be identified. The date when the reagent was made up, or received, should be on the label since some chemicals, particularly nitrogen compounds, become unstable with age.

7. When diluting concentrated acids or bases, always add slowly to the water allowing time to cool. Use only heat resistant (Pyrex) glassware. When diluting sulphuric acid or when making up a solution of sodium hydroxide, cool the solution in a water bath.

8. Chromic acid cleaning solution is a mixture of sodium or potassium dichromate in concentrated sulphuric acid. It dehydrates and oxidizes most organic matter, including clothing. TREAT IT WITH CARE!

9. Use water as a lubricant when making glass to hose connections. For vinyl tubing, hot water can be used to make the plastic more pliable. Gloves should be worn when making hose connections to glass tubing.

10. Suction bulbs should be used on all pipets. A valved type sold as a "PROPIPET" will save fumbling.

11. Combining chemicals found in the laboratory without knowing how they will react can produce unexpected and unpleasant results.

12. When disposing of any chemical in the sink, dilute with plenty of water.

13. Bottles of hazardous liquids should be stored near floor level in ventilated cupboards.

14. HASTE MAKES WASTE (and accidents). Planning can save far more time than hurrying (and produces fewer mistakes).

Characteristics of Dangerous Gases and Gas Fuels

Refer to Tables 10-1 and 10-2.

SAFETY PRACTICES IN WORK AREAS

The following paragraphs list some of the specific safety measures an operator should observe when carrying out his responsibilities in a plant.

No Smoking Areas

1. Chemical storage areas
2. Fuel storage areas
3. Wet and dry wells of plant pumping stations
4. Pump rooms
5. Tunnels having pipe galleries
6. Chlorine building
7. Manholes, tanks, reservoirs, excavations, trenches

Chlorine Buildings

1. The following signs must be posted outside the room door:
   a) Turn on Vent Fan
   b) Danger Chlorine Storage
2. A "Fresh Air" air pack must be located within 15 feet of room door.
3. An eye wash bath must be located within 15 feet of room door.
4. Mechanical ventilation of the chlorine room shall be sufficient to produce 30 air changes an hour taking suction from within 18 inches of the floor.
5. Operator must wear safety goggles and a pair of rubberized gloves.
6. Two operators shall be present for cylinder changing.

7. Fresh strong ammonia must be used for leak detection.

8. The chlorine room must NOT be used as a plant storage area.

Wet Wells

A wet well is classified as a confined space under Sec. 84-88 of the Industrial Safety Act, 1975. Before entering the operator must:

1. Test for oxygen content using an oxygen meter. DO NOT ENTER unless the oxygen content in the atmosphere registers between 18% and 23%.

2. Test the noxious gases and vapours using a combustible gas analyzer.

3. Test for Hydrogen Sulphide using the colorimetric test. Tests for other gases may also be necessary.

The operator must also take the following precaution on entry:

1. If any atmospheric contamination is suspected, a fixed or portable vent fan of 700 cfm capacity must be used before and during entry. If no vent fan is available, a portable air pack must be worn.

2. Explosion and waterproof lighting must be used.

3. An operator with a man hoist must be located at all times at the entrance to the wet well to monitor the meters and observe the operator inside.

4. If a man hoist is not available two operators must be at the entrance.

5. A parachute type harness and lifeline and hard hat must be worn.

6. A step-through parting is required at the ladder entrance.

Dry Well

1. Vent fan shall be started before entering the pumping station and left operating continuously while the operator is in the station.
2. "DANGER PUMPS ON AUTOMATIC CONTROLLER" signs should be posted at the control panel floor level, and the pump floor level.
3. "NO SMOKING" signs should be posted at the pump floor level.
4. Lock out switches at control panel when working on any pump at any floor level.

Pump Rooms

1. "Caution Pumps on Automatic" signs must be posted.
2. Vent fans must be on.

HANDLING CHEMICALS

In handling chemicals in the water treatment process, the general safety requirements outlined earlier should be met. Operators should be aware of the hazards associated with chemicals used in a water treatment.

Alum

Wear protective dust-proof equipment (goggles and nose mask) and proper clothing when handling and storing alum. Avoid skin and nose irritations by using plenty of water when washing and bathing.

Hydrofluosilic Acid

The vapour or liquid chemical is very dangerous when it comes into contact with the eyes, skin or any part of the body, or if taken internally.

Operator must wear protective clothing and equipment consisting of long gauntlet type rubber gloves, high rubber boots or waders, short type rubber raincoat and chemical safety goggles with a plastic face shield.

Fluoride Powders

Do not let dust touch skin or inhale fumes.

Air ventilation must be at least ten (10) air changes per hour.

Operator must wear good quality coveralls, rubber boots (knee length), rubber gloves or plastic coated cotton gloves with cuffs of half a forearm length; dust proof cap and rubber apron, plastic goggles, nose mask with replaceable filters approved by the U.S. Bureau of Mines for fluorides. The filter in the nose mask should be replaced each day or more frequently if required.

Showers must be available. All rubberized clothing should be hosed down at the end of a shift.

A urine sample must be submitted by each operator to the MOH once every three months.

Empty chemical bags must be deposited in a securely tied plastic bag at a sanitary landfill. *DO NOT BURN THESE BAGS.*

Sodium Chlorite

This chemical is highly explosive if it is in contact with organic matter. Store it in a clean, cool, dry area. Keep it away from open flame or heat. A "Metal X" fire extinguisher is the only type that will extinguish this material when on fire.

Ammonia

Store cylinders in a cool, dry, *ventilated* place. *Handle with care.* An air pack should be available. In case of cylinder leaks, only trained personnel should make repairs. *You must know your first aid if you handle and use this material.*

Activated Carbon

Store in a dry, fire-proof space. Wear protective, dust-proof equipment (goggles and nose mask) when handling activated carbon. *Do not smoke* while working with or near stored material. Use plenty of water when washing and bathing.

Lime

Use protective, dust-proof equipment (goggles and nose mask) while handling lime and use a dust collecting system, if possible. Store in a ventilated, dry area. Use plenty of water when bathing and washing to prevent irritations. Consult a physician if irritation becomes severe.

Soda Ash

Handle soda ash as described for lime. See above.

Solvents

Be careful when using solvents in confined areas. The area should be well ventilated. Clean solvents from skin to prevent irritations.

Table 10-1 CHARACTERISTICS OF DANGEROUS GASES ENCOUNTERED IN SEWERS, SEWAGE PUMPING STATIONS AND SEWAGE TRT PLANTS

GAS	CHEMICAL FORMULA	COMMON PROPERTIES*	SPECIFIC GRAVITY OR VAPOUR DENSITY (AIR=1)	PHYSIOLOGICAL EFFECT*	MAX SAFE 60-MIN EXPOSURE (% BY VOL. IN AIR)	MAX SAFE 8-HR EXPOSURE (% BY VOL. IN AIR)	EXPLOSIVE RANGE (% BY VOL. IN AIR) LOWER LIMIT	EXPLOSIVE RANGE (% BY VOL. IN AIR) UPPER LIMIT	LIKELY LOCATION OF HIGHEST CONCENTRATION	MOST COMMON SOURCES
CARBON DIOXIDE	CO_2	COLORLESS, ODORLESS WHEN BREATHED IN LARGE QUANTITIES MAY CAUSE ACID TASTE. NONFLAMMABLE. NOT GENERALLY PRESENT IN DANGEROUS AMOUNTS UNLESS O_2 DEFICIENCY	1.53	CANNOT BE ENDURED AT 10% MORE THAN FEW MIN, EVEN IF SUBJECT IS AT REST AND OXYGEN CONTENT NORMAL. ACTS ON RESPIRATORY NERVES.	4 TO 6	0.5	-	-	AT BOTTOM; WHEN HEATED MAY STRATIFY AT POINTS ABOVE BOTTOM	PRODUCTS OF COMBUSTION, SEWER GAS, SLUDGE. ALSO ISSUES FROM CARBONACEOUS STRATA.
CARBON MONOXIDE	CO	COLORLESS, ODORLESS, TASTELESS, FLAMMABLE, POISONOUS.	0.97	COMBINES WITH HEMOGLOBIN OF BLOOD. UNCONSCIOUSNESS IN 30 MIN AT 0.2 TO 0.25%. FATAL IN 4 HR AT 0.1%. HEADACHE IN FEW HR AT 0.02%	0.04	0.01	12.5	70.0	NEAR TOP, ESPECIALLY IF PRESENT WITH ILLUMINATING GAS.	MANUFACTURED GAS, FLUE GAS, PRODUCTS OF COMBUSTION, MOTOR EXHAUST, FIRES OF ALMOST ANY KIND.
GASOLINE	C_5H_{12} TO C_9H_{20}	COLORLESS, ODOR NOTICEABLE AT 0.03% FLAMMABLE.	3.0 TO 4.0	ANESTHETIC EFFECTS WHEN INHALED. RAPIDLY FATAL AT 2.4%. DANGEROUS FOR SHORT EXPOSURE AT 1.1 TO 2.2%.	0.4 TO 0.7	0.10	1.3	6.0	AT BOTTOM	SERVICE STATIONS, GARAGES, STORAGE TANKS, AND HOUSES.
HYDROGEN	H_2	COLORLESS, ODORLESS, TASTELESS. FLAMMABLE.	0.07	ACTS MECHANICALLY TO DEPRIVE TISSUES OF OXYGEN. DOES NOT SUPPORT LIFE.	-	-	4.0	74.0	AT TOP.	MANUFACTURED GAS, SLUDGE DIGESTION TANK GAS, ELECTROLYSIS OF WATER. RARELY FROM ROCK STRATA.

* PERCENTAGES SHOWN REPRESENT VOLUME OF GAS IN AIR.

Table 10-1 CHARACTERISTICS OF DANGEROUS GASES (CONTINUED)

GAS	CHEMICAL FORMULA	COMMON PROPERTIES*	SPECIFIC GRAVITY OR VAPOUR DENSITY	PHYSIOLOGICAL EFFECT *	MAX SAFE 60-MIN EXPOSURE (% BY VOL. IN AIR)	MAX SAFE 8-HR EXPOSURE (% BY VOL. IN AIR)	EXPLOSIVE RANGE (% BY VOL. IN AIR) LOWER	EXPLOSIVE RANGE (% BY VOL. IN AIR) UPPER LIMIT	LIKELY LOCATION OF HIGHEST CONCENTRATION	MOST COMMON SOURCES
HYDROGEN SULFIDE	H_2S	ROTTEN EGG ODOR IN SMALL CONC. EXPOSURE FOR 2 TO 5 MIN AT 0.01% IMPAIRS SENSE OF SMELL. ODOR NOT EVIDENT AT HIGH CONC. COLORLESS. FLAMMABLE.	1.19	IMPAIRS SENSE OF SMELL RAPIDLY AS CONC. INCREASES. DEATH IN FEW MIN AT 0.2% EXPOSURE TO 0.07 TO 0.1% RAPIDLY CAUSES ACUTE POISONING. PARALYZES RESPIRATORY CENTER.	0.02	0.002	4.3	46.0	NEAR BOTTOM, BUT MAY BE ABOVE BOTTOM IF AIR IS HEATED & HIGHLY HUMID.	COAL GAS, PETROLEUM SEWER GAS. FUMES FROM BLASTING UNDER SOME CONDITIONS SLUDGE GAS.
METHANE	CH_4	COLORLESS, ODORLESS, TASTELESS. FLAMMABLE	0.55	ACTS MECHANICALLY TO DEPRIVE TISSUES OF OXYGEN. DOES NOT SUPPORT LIFE.	PROBABLY NO LIMIT PROVIDED OXYGEN PERCENTAGE IS SUFFICIENT FOR LIFE.		5.0	15.0	AT TOP, INCREASING TO CERTAIN DEPTH.	NATURAL GAS, SLUDGE GAS, MANUFACTURED GAS, SEWER GAS. STRATA OF SEDIMENTARY ORIGIN. IN SWAMPS OR MARSHES.
NITROGEN	N_2	COLORLESS, TASTELESS. NONFLAMMABLE. PRINCIPAL CONSTITUENT OF AIR (ABOUT 79%).	0.97	PHYSIOLOGICALLY INERT	-	-	-	-	NEAR TOP, BUT MAY BE FOUND NEAR BOTTOM.	SEWER GAS, SLUDGE GAS. ALSO ISSUES FROM SOME ROCK STRATA.
OXYGEN (IN AIR)	O_2	COLORLESS, ODORLESS.	1.11	NORMAL AIR CONTAINS 20.93% OF O_2. MAN CAN TOLERATE DOWN TO 12% MIN SAFE 8-HR EXPOSURE, 14 TO 15%. BELOW 10% DANGEROUS TO LIFE. BELOW 5 TO 7% PROBABLY FATAL.	-	-	-	-	VARIABLE AT DIFFERENT LEVELS.	OXYGEN DEPLETION FROM POOR VENTILATION AND ABSORPTION, OR CHEMICAL CONSUMPTION OF OXYGEN.
SLUDGE GAS	-	MAY BE PRACTICALLY ODORLESS, COLORLESS.	VARIABLE	WILL NOT SUPPORT LIFE.	NO DATA. WOULD VARY WIDELY WITH COMPOSITION.		5.3	13.3	NEAR TOP OF STRUCTURE.	FROM DIGESTION OF SLUDGE.

* PERCENTAGES SHOWN REPRESENT VOLUME OF GAS IN AIR.

Table 10-2 CHARACTERISTICS OF GAS FUELS

GAS	CHEMICAL FORMULA	B. T. U. CALORIFIC VALVE	SPECIFIC GRAVITY OR VAPOUR DENSITY	EXPLOSIVE LIMITS IN AIR % BY VOLUME		THEORECTICAL AIR REQUIRED FOR COMPLETE COMBUSTION	MINIMUM IGNITION TEMPERATURE °FAHRENHEIT	MAXIMUM FLAME TEMPERATURE °FAHRENHEIT	FLAME SPEED PER SEC.	AUTO IGNITION TEMPERATURE
				LOWER	UPPER					
METHANE	CH_4	913.1	0.55	5	15	9.56 TO 1	1170°	3484°	0.85	1000
NATURAL GAS		1027	0.6	4.9	15	10.00 TO 1	1170°	3562°	0.99	1000
PROPANE	C_3H_8	2385	1.52	2.10	10.10	23.9 TO 1	898°	3573°	0.95	871

TAKEN FROM FACTORY MUTUAL'S HANDBOOK OF INDUSTRIAL LOSS PREVENTION. CHAPTER 37

SUBJECT:

PROCESS CONTROL TESTS

TOPIC: 11

Jar Tests

OBJECTIVES:

The trainee will be able to:

1. Recall the purpose of jar tests;
2. Prepare stock chemical solution;
3. Demonstrate the procedure for carrying out a jar test;

JAR TESTS

PURPOSE

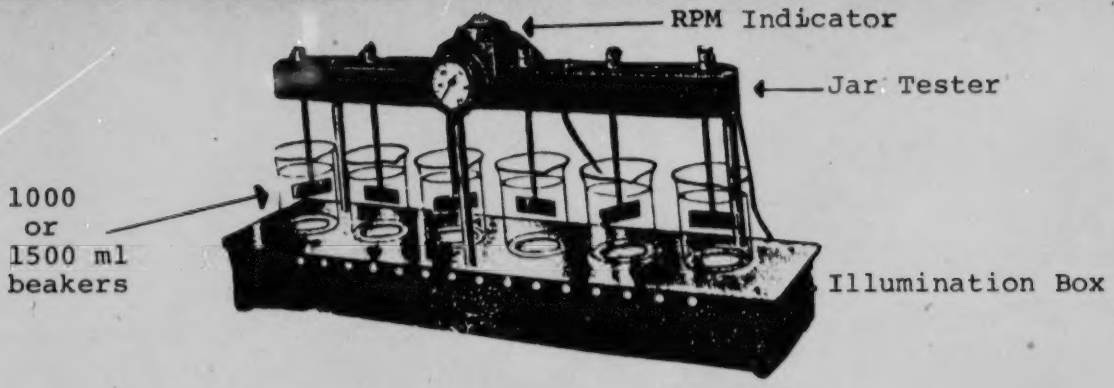
Jar tests are used to determine the correct amount of coagulant.

The following chart indicates the advantages of using the proper dosage of alum solution as a coagulant:

	Under Dose	Proper Dose	Over Dose
Turbidity removal	Poor	Good	Fair
Colour removal	Poor	Good	Fair
Algae removal	Poor	Good	Fair
Length of filter runs	Medium	Long	Short
Residual aluminum	High	Low	High
Dollar value	Wasted	Good	Poor

EQUIPMENT REQUIRED (See illustrations on page 11-2)

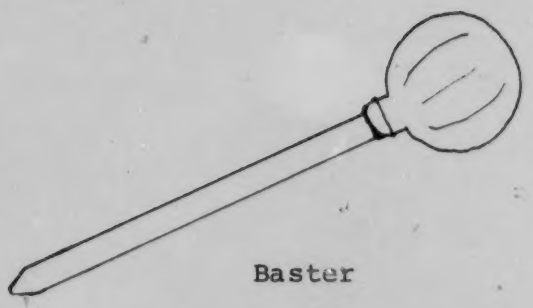
1. Jar Tester (4 or 6 paddles)
2. Illuminator Box (preferred but not essential)
3. Beakers - 6 (100 or 1500 ml capacity)
4. Pipettes - 5 1-ml graduated (glass)
5. Erlenmeyer Flasks - 6 250-ml capacity
6. Funnels - 6 ribbed, conical 2.5 inch diameter, short stemmed
7. Graduated Cylinders - 2 100-ml (plastic or glass)
   1 1000-ml (plastic or glass)
8. Filter Paper - 11 cm. S&S Black Ribbon 589, or Whatman #41
9. Baster
10. Scale - accurate to 1/20 of a gram
11. Bacteriological sampling bottles - no preservative.



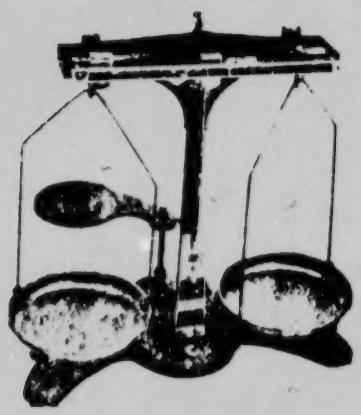
Erlenmeyer Flask

Graduated
Cylinder

Conical Ribbed
Funnel



Baster



Scale

Figure 11-1 Jar Test Equipment

TREATABILITY TEST SHEETS

An example of a helpful guide for carrying out the jar test is illustrated in Table 11-1. Your raw water analysis should be carried out and entered in the Raw Water Analysis Section (upper left corner). With this analysis complete, the operator is ready to carry out the various jar test steps.

CHEMICAL SOLUTIONS

Stock solutions of coagulants, coagulant aids and other chemicals should be prepared at concentrations such that quantities suitable for use in coagulation tests can be measured accurately and conveniently.

Chemical	Concentration of Stock Sol.	Prepare Fresh Solution After	1 ml in 1000 ml of H_2O Equiv. to
Alum	1%	1 month	10 mg/l
Ferric Chloride	1%	2 months	10 mg/l
Activated Silica	1%	2 days	10 mg/l
Polyelectrolyte	0.05%	1 week	0.5 mg/l
Sulphuric Acid	0.1N	3 months	4.9 mg/l

NOTES:

- Alum - 1% solution can be made by adding 1 g of powdered alum to 100 mls of water OR 1.54 mls of liquid alum to 100 mls of water.
- Activated Silica solutions necessary for the preparation of a 1% solution can be obtained through your Ministry of the Environment regional engineer.
- Polyelectrolyte solutions should be used with the guidance of the manufacturers.

TURBIDITY	J.T.U.
COLOUR	HAZEN
pH	
FLOC TEMPERATURE	
ALKALINITY	MG/L
HARDNESS	MG/L
IRON	MG/L
CHLORINE	MG/L

DATE

LOCATION

RAW WATER ANALYSIS
RUN NO.

SOURCE

CHEMICALS					pH		FLOC			SUPER-NATANT	FILTERED SUPERNATANT ANALYSIS							
JAR #	MG/L	MG/L	MG/L	MG/L	* INITIAL	FLOC	SPEED	SIZE 20 MIN	SETTING RATE	20 MIN SETTLED TURBIDITY	30 MIN TURBIDITY	pH	COLOR	AL MG/L	FE MG/L	ALK MG/L	HARDNESS MG/L	
1																		
2																		
3																		
4																		
5																		
6																		

* Same as raw unless chemical added prior to addition of coagulants.

STIRRING TIME SPEED G+/1000

MINUTES @ RPM sec^{-1}
MINUTES @ RPM sec^{-1}
MINUTES @ RPM
SETTLING TIME MIN

TREATABILITY
Table 11-1 COAGULATION TESTS

Solution Preparation

Alum and Ferric Chloride

Both alum and ferric chloride are usually prepared as a 1% solution by weight (that is 1 g in 100 mls or 1 lb. in 100 lbs). If one has dry alum or ferric chloride the preparation is straight forward. With concentrated liquid solutions (e.g. alum 48.5% by weight) a dilution step has to be done. Any dilution step has to take into account the specific gravity (s.g.)* of the solution being diluted, e.g. 48.5% alum has a s.g. of 1.35. To make up a one percent solution from liquid alum we carry out the following steps:

1 ml of 48.5% liquid alum weighs 1.35g

1 ml contains $1.35 \times \frac{48.5}{100} = 0.65$ g

# of mls containing 1 g $= \frac{1}{0.65} = 1.54$

Therefore add 1.54 mls (or 1 g) of liquid alum to 100 mls to make up a 1% solution.

Note: * weight of solution divided by unit volume (g/cc)

Sample Problems

1. Prepare a 1% solution of ferric chloride if the concentrated solution of 42.3% by weight and the specific gravity is 1.42.

2. How many mls of storage tank alum are required to make up 100 mls of a 1% solution for jar tests if the alum is 48% by weight (s.g. 1.34) when delivered, but diluted 2:1 at the storage tank.

Activated Silica Solution for use in Jar Tests

1. Stock Solution of Sodium Silicate

Weight 348.4 grams of sodium silicate solution "N" Brand, sodium silicate solution as made by Philadelphia Quartz Co., Philadelphia, Pa., U.S.A., and National Silicates Limited, Toronto, Ontario). Dissolve this sodium silicate solution in 500 ml. of distilled water and then dilute to one litre with distilled water. If capped in bottles, this solution will remain stable indefinitely.

2. Stock Ammonium Sulphate Solution

Weight 66.0 grams of ammonium sulphate $(NH_4)_2SO_4$. Dissolve in 980 ml. distilled water. Kept in capped bottles, this solution is stable indefinitely.

3. Preparation of the Activated Silica Solution

a) Place 20 ml. distilled water in a 100 ml graduated cylinder. Add 10. ml. of stock sodium silicate solution and invert four times to mix.

b) Add 10. ml. stock ammonium sulphate solution and invert 10 times to mix. Let this mixture age for 5 minutes, exactly. Then dilute to 100 ml. with distilled water and invert 10 times to mix. The activated silica solution is now ready for use in the Jar Test. It should be made fresh daily.

c) Each 0.1 ml. of this activated silica solution represents a dosage of 1.0 part per million when added to a one litre water sample in the Jar Test, and, therefore, 1.0 ml. of this activated silica solution represents 10. parts per million of activated silica when added to a one litre sample of water in the Jar Test.

Activated Silica on a Plant Scale (See Page 11-9)

1. To make a 1% Activated Silica Solution:

   a) take 1 gal. of sodium silicate (N - sol. 28.7% SiO_2) and mix with 18 gal. of water.

   b) slowly dissolve 3½ lbs. of sodium bicarbonate in 8 gal. of water

   c) mix a) and b) together and age for 2 hrs., then dilute to 41.6 gal.

2. Alternate Method Using a Mixer

   a) mix 1 gal. of sodium silicate (N - sol. 28.7% SiO_2) with 26 gal. of water

   b) using a mixer, mix at high speed and sprinkle 3½ lbs. of sodium bicarbonate into it until all is dissolved, age for 2 hours, then dilute to 41.6 gal.

Places in Ontario Using Activated Silica

Location	Dosage (mg/l)	Location	Dosage (mg/l)
Blenheim	2	Brantford	7
Cayuga	4	Kingsville	2
Emo	4	Petrolia	
Huntsville	2	Lindsay	
Amherstburg	2.5	Dresden	
Goderich	2	Campbellford	
Haileybury	12	Belle River	
Oakville	2	Thornbury	
Port Hope	2		

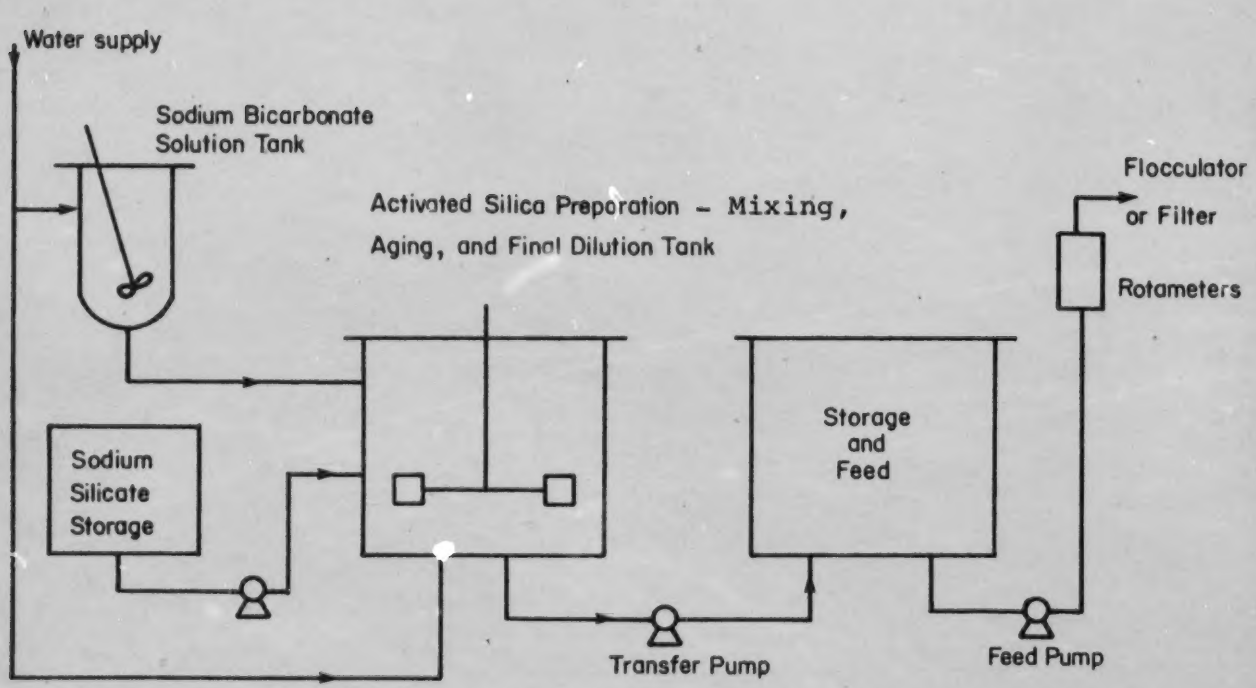


Figure 11-2 Activated Silica Equipment Arrangement

Polymer

Care must be taken when making up polymer solution for jar tests from powdered polymers. Fish eyes or globs of polymer result if the polymer is added to the solution too quickly or if solutions greater than 1% are attempted to be made. It is recommended that 0.05% or 0.1% be made up for jar tests. As the water is being added to the bottle the polymer should be added very slowly to "wet" it as it enters the container. For plant use, a polymer eductor is used. Page 11-14 lists Polymers in use in Ontario and suppliers.

Note

- 1 ml of 1% polymer added to 1000 mls water = 10 mg/l
- 1 ml of 0.1% polymer added to 1000 mls water = 1 mg/l
- 1 ml of 0.05% polymer added to 1000 mls water = 0.5 mg/l

TEST PROCEDURES

Jar Tests Using Coagulants Only

Jar Tests using coagulants only require a 6-place laboratory stirrer or jar tester, as well as six 1500 ml beakers. The procedure for carrying out the test is:

1. Under each stirring paddle, place a 1500 ml beaker
2. Place into each beaker, from a graduated cylinder, exactly 1000 ml of a fresh sample of the raw water.
3. Note on the test sheet the amount of coagulant that you are going to add to each beaker. This amount will vary from beaker to beaker.
4. Start the stirrer and set it at maximum speed (usually 100 + rpm).
5. Add the coagulant in increasing amounts to each successive beaker. For example, 10 mg/l to beaker #1, 20 mg/l to beaker #2, etc.

NOTE: 1 ml of 1% solution in 1000 ml of water is 10 mg/l

6. After the coagulant dosage has been added to the last beaker, continue running the stirrer at maximum speed (100 + rpm) for another minute.
7. Reduce the speed to 30 rpm and allow the stirring to continue for 30 minutes.
8. Note how long it takes before a floc begins to form
9. Note how well it withstands some stirring without breaking up.
10. Stop the stirrer after 30 minutes. Note how long it takes for the floc to settle to the bottom of the beaker.
11. After allowing the floc to settle for 20 minutes, note the colour and the turbidity of the supernatant (the liquid above the floc). This sample is obtained by using a baster.
12. Remember to note your chemical dosages, mixing time and speed, pH, floc growth characteristics and supernatant analysis on your operating sheets.

13. After allowing the floc 30 minutes to settle to the bottom, filter the supernatant, using the baster as a sampler, through S & S Black Ribbon #589 filter paper (other coarse filter papers are acceptable).
14. Since many filter papers will give off particular matter early in the filtration, the first 75 - 100 mls of sample should be disregarded.
15. Filter another 100 - 150 mls of sample.
16. Perform turbidity, pH, colour and residual aluminum tests on the filtrate.
17. If you have an iron coagulant or a high iron level in your raw water, carry out an iron test on the filtered water.
18. The hardness test is essential in both a softening and a partial softening plant.
19. The alkalinity test is important in soft waters. It can also be used to check your alum dosage. Remember 1.0 mg/l alum reduces the alkalinity by 0.45 mg/l.
20. The jar that gives the best results using the least amount of coagulant should indicate the proper coagulant dosage for your plant.

Jar Tests Using Coagulants Plus Flocculation Aids

1. To determine if either activated silica or polyelectrolyte can help the coagulation-flocculation-sedimentation process, do the following: Repeat the jar test using the best coagulation dosage as determined from step 20 above (or slightly below this dosage), and add varying amounts of flocculant aid as described at step 5 above for the addition of the coagulant. The amount of activated silica added is usually 10 to 20% of the alum dosage used. Polyelectrolyte dosages rarely exceed 1 mg/l.
2. When determining the use of flocculation aids, keep one jar with alum only. Then compare the results when using only alum to the results obtained when a flocculation aid is added to the alum.

3. When applying jar test results to the plant, it is sometimes found that the plant operates better at a chemical dosage slightly different than that indicated by the jar tests. The jar testing is very efficient both in stirring and settling. If the plant is not as efficient as the jar tests, a higher dosage of coagulant may be needed.

4. The regional or district staff of the Ministry of the Environment should be contacted when difficulties arise either in trying to run the jar tests, or in trying to apply the jar test results to the plant.

Table 11-2 Polymers and Suppliers

Manufacturer	Address	Products
Alchem Limited (Nalco Chemicals Ltd.)	211 Lakeshore E Oakville, (416) 849-7121 or Zenith 81930	Nalcolyte Series
Allied Colloids Inc.	151 Carlingview Dr. Toronto (416) 678-6020	Percol Series
Calgon Corp.	27 Finlay Brampton (416) 457-5310	Coagulant Aid Series Cat Floc Series
Cyanamid of Canada Ltd.	2031 Kennedy Rd. Toronto (416) 293-8181	Superfloc Series Magnifloc Series
Dearborn Chemicals	3451 Erindale Stn. Rd. Mississauga (416) 279-2222	Aquafloc Series
Dow Chemical	250 Bloor E. Toronto (416) 920-5520	Separan Series purifloc Series
Drew Chemical Co.	Drewcourt Ajax (416) 925-3069	Drewfloc Series

Polymers in Use in Ontario

Location	Product	Approx. Dosage	Use
Arnprior	Nalcolyte 8170	0.02 mg/l	Filter Aid
Lakefield	Nalcolyte 8174	0.5 mg/l	Flocculant Aid
Lake Huron WSS	Separan NP-10	0.05 mg/l	Filter Aid
Moosonee	Separan NP-10	0.5 mg/l	Flocculant Aid
Ohsweken	Cat Floc	1.0 mg/l	Flocculant Aid
Petawawa	Separan NP-10	-	
Rockland	Nalcolyte 8170	0.3 mg/l	Flocculant Aid
Sarnia	Purifloc N-20	0.01 mg/l	Filter Aid
Sudbury	Purifloc A-22	0.5 mg/l	Flocculant Aid
Timmins	Nalcolyte 8170	0.8 mg/l	Flocculant Aid
Windsor	Percol LT 24	0.1 mg/l	Primary Coagulant

Important

Before using any polymer in the treatment process always consult the supplier regarding the toxicity and maximum dosages of the polymer.

SUBJECT:

PROCESS CONTROL TESTS

TOPIC: 12

- pH
- Alkalinity
- Calcium and Magnesium Hardness

OBJECTIVES:

The trainee will be able to carry out and/or describe the methods for determining:

1. the pH of the water by visual or electrometric methods;

2. the hydroxide, carbonate and bicarbonate alkalinity of a given water;

3. the total and calcium hardness.

pH

pH is a term that is used to express the level or intensity of the acid or alkaline conditions that prevail in a sample. Technically speaking, pH can be described as the logarithm of the reciprocal of the hydrogen ion concentration, but in colloquial language, it is a scale for measuring acidity in the same way as Centigrade or Fahrenheit is a scale for measuring temperature.

Soon after Hydrogen was discovered a little over 200 years ago, it became apparent that all acids contained this element, and, on neutralizing an acid with an alkaline substance, water was produced among other things. It was found that such water contained a hydrogen ion concentration of 10^{-7} mole/l. Since this same pure neutral water, when dissociated, gave one hydroxyl for every hydrogen ion present, it could be readily seen that the same concentration of the hydroxyl ion was also present (namely, 10^{-7} mole/l of hydroxyl ion).

In aqueous solutions the product of the concentrations of the hydrogen ion and the hydroxyl ion is always a constant, so that the hydrogen ion concentration of a scale starting from strong acid, going through neutral to strong alkali, would look like this:

STRONG ACID	WEAK ACID	NEUTRAL POINT	WEAK ALKALI	STRONG ALKALI

0	-1	-2	-3	-4	-5	-6	-7	-8	-9	-10	-11	-12	-13	-14
10	10	10	10	10	10	10	10	10	10	10	10	10	10	

HYDROGEN ION CONCENTRATION IN MOLES PER LITRE

The Danish Technician S.P.L. Sorenson took the next logical step and introduced the pH symbol and scale which looked thus:

STRONG ACID			WEAK ACID			NEUTRAL POINT			WEAK ALKALI			STRONG ALKALI		
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14

pH UNITS

Before discussing pH measurement, it must be emphasized that the pH of a sample is only a measure of the level of acidity or alkalinity in a sample, (i.e. degree of ionization) and not a measure of total acidity or alkalinity.

If a decinormal (1/10) Sulphuric acid solution, and a decinormal Acetic acid solution are titrated one at a time, against the same alkali solution, they both have the same neutralizing potential. However, if pH determinations are made on both of them, the sulphuric acid has a pH of approximately 1, whilst the acetic acid has a pH of about 3. This happens because the latter has a lower degree of ionization, hence its pH is higher.

METHODS OF pH MEASUREMENT

1. Visual

Dyes (Indicators) which change colours at certain pH ranges are added to the sample which has been placed in a Nessler tube or Comparator cell. The colour produced is measured in a Nesslerizer or Comparator against standard coloured glass discs.

Visual methods of determining pH are subject to error in the range of ±0.1 pH units. This error could stem from one, or any combination, of the following factors:

a) The human factor, i.e. poor judgment combined with questionable eyesight.

b) Accepting a reading made at either end of the range of the standard disc (only mid-point of the range is used).

c) Waters with low dissolved solids (hence low buffering capacities) do not give the right intensities of developed colour with the indicator.

d) Colour in the water makes matching difficult.

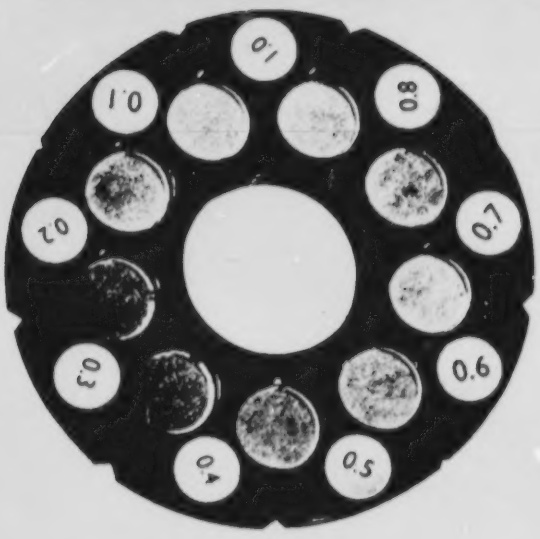
e) Wide variations in sample temperature of the glass standards affects intensity of colour.

f) Inaccurate addition of the recommended quantity of the indicator to the sample. (Quite critical in some cases).

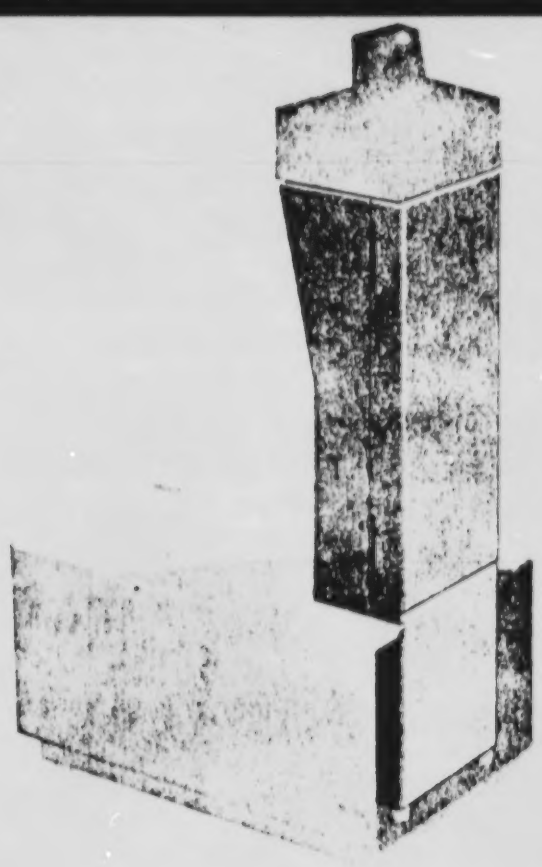
The use of indicators accurate for pH can only be considered useful when the following conditions apply:

a) Measurement of pH is not too critical, i.e. ±0.1 pH error is within the tolerance required.

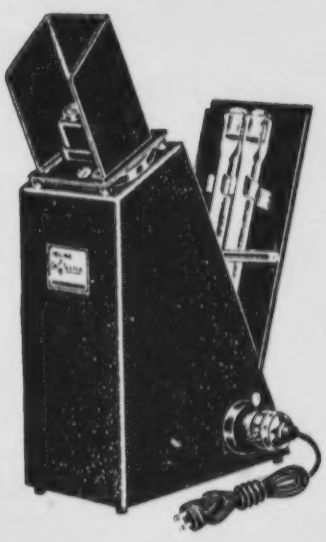
b) Lack of technical knowledge, or practical experience of personnel prohibits the introduction of electrometric methods in making pH measurements.



COLOUR DISK



BDH LOVIBOND NESSLERIZER WITH LIGHTBOX



HELLIGE AQUA TESTER

FIGURE 13-1 COLOUR DETERMINATION APPARATUS

2. Reagents and Apparatus Required:

B.D.H. Lovibond Nesslerizer

2 x 50 ml Nessler Tubes

Discs containing permanent glass colour

Standard 0.2 ml Pipettes

pH Indicators	pH Range
Bromo Cresol Purple	5.2 - 6.8
Bromo Thymol Blue	6.0 - 7.6
Phenol Red	6.8 - 8.4
Cresol Red	7.2 - 8.8

3. Procedure

Select the disc and indicator so that the pH of the sample to be measured falls near the midpoint of its range.

a) Place 50 mls of the sample in each of the two Nessler tubes.

b) Using the tube as a blank put it in the left hand compartment of the Nesslerizer, i.e. the part under the glass standards.

c) Add 0.2 ml of indicator to the other Nessler tube, mix it well and place it in the right hand compartment.

d) Facing the instrument towards a North window, rotate the disc in the hinged lid and take a reading when a colour match is obtained.

Electrometric

1. Principle of Operation

A measurement is made of the millivoltage that is produced, when a sample and a couple of electrodes of a special type are set up as a galvanic cell. The number of millivolts produced depends on the level of acidity in the cell system.

2. Method of Operation

Several varieties of pH meters are in use. (See figure 12-1). The basic method for the operation of such instruments can be summarized as follows.

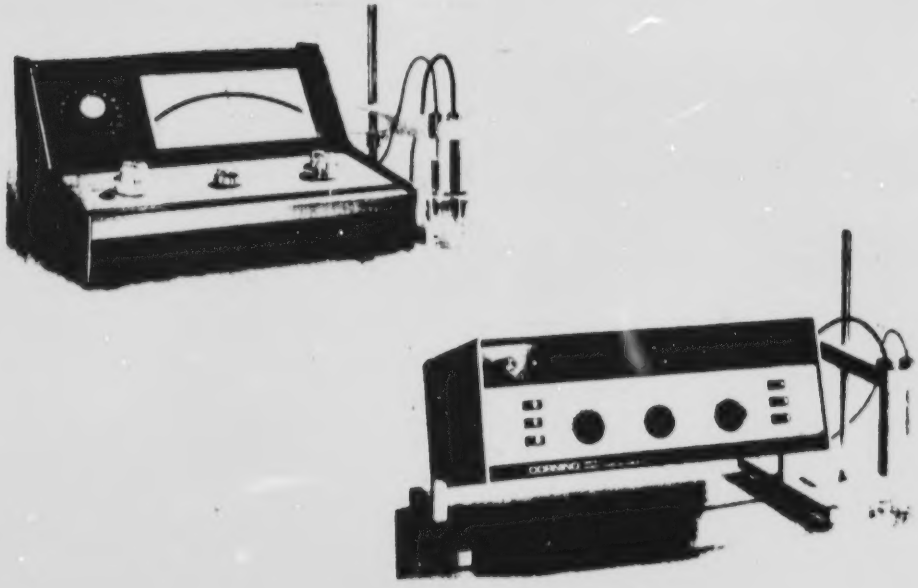


Figure 12-1 pH Meters

a) Turn the instrument on and wait till it is warmed up.

b) Set the temperature at which the pH is to be measured.

c) Calibrate the instrument with a standard Buffer Solution (while stirring).

d) Remove the buffer and rinse the electrodes well.

e) Place the electrodes in the sample and while stirring read the pH.

f) Remove the sample, rinse the electrodes well and keep them immersed in distilled water.

3. Important Points to Remember

a) Always keep the electrodes in distilled water when the pH meter is not in use.

b) Measure at room temperature when most precise measurements are required.

c) The pH of the buffer used to calibrate the instrument should always be as near as possible to the pH of the sample being measured.

d) A check buffer which differs at least by 2pH units should always be kept at hand to check the calibration buffer. pH4 buffer is recommended for calibrating and pH7 for checking, or vice versa, whichever one is nearer the sample. On a good meter the reading on the check buffer should not be more than $\pm$0.02 pH units.

e) pH4 buffer is the most stable buffer and pH9 is the most unstable buffer.

f) The level of saturated Potassium Chloride (KCl) in the calomel reference electrode should always be higher than the level of the liquid that is being measured for pH. A few crystals of KCl should always be visible in the electrode.

g) If the glass electrode has been stored in a dry condition it should be immersed for 4-6 hours in an 0.1 N Hydrochloric acid at room temperature. This procedure should also be carried out when the electrodes become sluggish.

(Note: 0.1 N Hydrochloric Acid = 9 mls concentrated Hydrochloric acid in 1 litre of distilled water.)

h) The most common defect that causes poor pH results is a badly scratched or cracked membrane (i.e. the glass bulb at the end of the glass electrode). Cracks may occur if the membrane is just only rubbed against the bottom or sides of a beaker.

HARDNESS

General

A water is considered hard when instead of forming a copious lather with a good soap it just produces a scum. If this happens the cleaning capacity of the soap and water are greatly reduced.

The causes of hardness stem from the presence of Calcium and Magnesium salts in the water. Iron, Aluminium, Manganese and a few other substances also produce hardness, but to such a small degree relative to the Calcium and Magnesium salts, that the latter need not be considered as significant contributors to the level of hardness in water. Thus only total hardness and Calcium hardness are determined.

Ground waters are generally harder than surface waters because the former probably have greater possibilities of picking up Calcium and Magnesium salts by flowing under high pressure through geological strata rich in such salts.

The following scale could be used as a reasonable guide to describe a water in terms of degree of hardness.

0	-	25 mg/l	VERY SOFT
25	-	75 mg/l	SOFT
75	-	150 mg/l	MODERATELY HARD
150	-	300 mg/l	HARD
300 and higher			VERY HARD

Total Hardness Measurement

1. Apparatus and Reagents Required

50 ml Pipette
250 ml Erlenmeyer Flask (Conical flask)
Automatic Burette
0.02N Ethylene Diamine tetra acetic acid
Odourless buffer. (This buffer is more stable than the Ammonia or Sulphide one)
Eriochrome Black T indicator solution or
Manver II powder pillows.

2. Procedure

a) Rinse the pipette and flask with the sample to be used and carefully drain them.

b) Measure 50 mls of the sample into the flask.

c) Add 1 ml of odourless buffer, and swirl to mix.

d) Add 10 drops of Erichrome black T solution or 1 Manver II powder pillow.

e) Titrate the sample with the standard 0.02N EDTA from the burette till the sample colour changes from a wine red to a permanent pure blue.

f) Multiply the mls. of titrant (EDTA) used in the titration by 20 (factor for a 50 ml aliquot) to obtain the mg/l total hardness expressed as Calcium Carbonate.

3. Calculation

Sample Portion (aliquot) = 50 mls
Titrant Used = 8.3 mls
Total Hardness = Titrant Used x $\frac{1000}{\text{aliquot}}$

$= 8.3 \times \frac{1000}{50}$

= 166 mg/l.

4. Points to Remember

a) The reaction between EDTA, Calcium and Magnesium is not instantaneous, hence the titrant should be added very slowly, when the end point of the titration is approaching. This allows time for the reaction and colour changes to take place.

b) If after adding 18-20 mls or more of the EDTA there is no colour change in the sample then either one or a combination of the following reasons might account for the situation.

(i) There is possibly too much interference from iron and/or copper.

(ii) The sample is extremely hard, i.e. more than 400 mg/l total hardness.

(iii) The required pH for the reaction has not been attained by the addition of 1 ml of the buffer because of the water's initial low pH and high buffering capacity.

c) The solutions to the problems in b) above are as follows:

(i) Add approximately 0.5 gm of Sodium Cyanide to eliminate Iron and Copper interference.

CAUTION: Cyanide is extremely poisonous. Wash your hands carefully before eating. Do not allow the Cyanide to come in contact with acid because Hydrogen Cyanide is evolved and this is a deadly toxic gas.

(ii) Dilute the sample, taking 100 mls and making it up to 500 mls in a graduated flask with distilled water. Analyse the contents of the flask and multiply the result by the factor of 5 (i.e. after multiplying by the factor of 20 if a 50 ml aliquot was taken from the diluted sample).

(iii) Add 0.5 to 1.0 ml more Odourless buffer. This amount should take the pH up to the required level.

Calcium Hardness Determination

1. Apparatus and Reagents Required

50 ml Pipette
250 ml Erlenmeyer flask
Automatic Burette
Indicator Murexide tablets or 1 Calver II powder pillow
0.02N E.D.T.A.
Buffer 8N Potassium Hydroxide.

2. Procedure

a) Rinse the pipette and flask with the sample and drain them well.

b) Measure 50 mls of the sample into the flask.

c) Add 1 ml of Potassium Hydroxide Buffer and swirl to mix.

d) Then add either 1 Murexide tablet or 1 Calver II powder pillow.

e) Titrate the sample with the standard 0.02N EDTA from the burette, till the sample changes in colour from red to a permanent pure blue.

f) Multiply the mls of titrant used in the titration by 20 (when a 50 ml aliquot is used). The figure then obtained gives the mg/l calcium hardness expressed as Calcium Carbonate.

3. Points to Remember

a) Magnesium must be present during the titration to obtain a sharp end point. Buffer containing Magnesium complexed with EDTA must be used.

b) The interferences that apply to total hardness also apply to calcium hardness determinations. They can be overcome by the same way.

SUBJECT:

PROCESS CONTROL TESTS

TOPIC: 13

Tests to Determine Physical Parameters
- Colour
- Turbidity
- Solids
- Taste and Odour

OBJECTIVES:

The trainee will be able to describe and/or demonstrate:

1. the use of the Lovibond Nesslerizer and the Hellige Aquatester for colour determination;

2. the use of the Hellige and the Hach turbidimeters for turbidity determination;

3. the methods of determining the total, suspended and dissolved solids in a water sample.

TESTS DETERMINING PHYSICAL PARAMETERS

GENERAL

The chemical processes that raw water may have to undergo in order to make it esthetically pleasing, reasonably palatable, and safely consumable, depend upon a number of variable chemical parameters which are responsible for giving each raw water its own individual characteristics. The diversity of types of water stems from the close contact it has had with varying geological basins, human pollution, and (decaying and growing) vegetation.

From the standpoint of the consumer, the physical parameters are the only ones he can readily observe with his unaided senses and upon which he bases his judgment on the effectiveness of the treatment that is given to the water that he consumes in his every day living. Thus this topic considers the laboratory procedures related to colour, turbidity, settleable solids, taste and odour.

COLOUR

Water is colourless by itself. When it leaches out high concentrations of iron and manganese from certain types of terrain, or organic substances from decaying vegetation, it takes on a brownish tint. Colour is a common constituent of some surface waters, and it can be attributed to the presence of non-toxic complex organic compounds.

Definition of Colour

When 1 milligram of Platinum present as chloro-platinate is combined with the appropriate amount of Cobalt Chloride, and they are dissolved in one litre of distilled water, then the ensuing colour from this standard is considered to be 1 HAZEN UNIT.

Analytical Technique for Colour Determination

1. Apparatus Required (See Page 13-4)

   a) Lovibond Nesslerizer, with discs containing glass standards

   OR

   b) Hellige Aquatester with discs containing glass standards.

   Both of these instruments use the same method, a straight comparison technique.

2. Procedure

   a) Fill one of the tubes supplied with the instrument to the 50 ml mark with the sample.
   b) Place it in the right hand compartment of the instrument (i.e. under that part of the disc without the glass standards).
   c) Fill the second tube with distilled water, and place it in the other compartment.
   d) Face the instrument towards a north window (or switch on the illuminating white light that can be obtained with the instrument, as an accessory).
   e) Rotate the disc containing the colour standards until a match is obtained. Note the number appearing in the aperture on the top of the instrument. This number is the result in Hazen Units.

3. Points to Remember

   a) When colour is caused by suspended matter, then an analysis sheet must append the comment "APPARENT COLOUR" directly after the result.

   b) If the colour is caused by a material that is in solution, then the words TRUE COLOUR should follow the result.

c) If a request is received for a true colour determination on a sample that obviously contains suspended matter which contributes in some degree to its colour, under no circumstances should the sample be filtered, because adsorption on the filtering medium might result in a lessening of the true colour. In such cases centrifuging of the sample is the only permissible way of separating the suspended matter from it.

d) Should the colour sample be darker than 70, which is the maximum reading that can be taken on the disc supplied with the instrument, it is permissible to make dilutions with good distilled water to bring the colour into a readable range. In this case, the result obtained must be multiplied by the dilution factor. However, in such cases discs with lighter ranges are available and their use is preferable.

N.B. - Experience has shown us that the colour value obtained is often only valid for the pH at which the determination was made. If the pH is either raised or lowered, the intensity of the brownish colour very often becomes darker or lighter. A good discipline, therefore, demands that we should always include the pH figure when a colour determination result is submitted on a report.

TURBIDITY

Definition

Haze or turbidity in water is caused by suspended particles in it. The particles interfere with the passage of light through the water, and depth of visibility is curtailed in it. This depth of visibility decreases as the concentration of the suspended matter increases.

Units of Measurement

There are several units currently used for the expressing or recording of turbidity concentration. They are as follows:

- ppm Silver Chloride, ppm Barium
- Sulphate, ppm Celite, ppm Formazin,
- ppm Silicate, Silica Units,
- Absorptiometric Turbidity Units,
- Nephelo Unit, Helm Unit, and the
- Jackson Turbidity Unit sometimes called the Formazin Turbidity Unit, or Nephelometric Turbidity Unit (NTU), when Formazin or some other polymer is used as the calibrating material.

Based on findings, optical units seemed to be the most appropriate way of expressing turbidity concentration. The most misleading unit was ppm. The implication of this unit is that the weight of the suspended material causing the turbidity is actually known. This is certainly not true when a variety of materials compose the suspension and their percentage concentration of the total suspension is varying continuously. In such a case the relative densities of the materials together with their individual concentrations would have to be known at any given moment in order to arrive at a true ppm value; which would only be valid for that moment. The only time that the ppm scale is correct is when the material that has been used in calibrating the scale is precisely the same as the suspension of the sample being measured, and this must include the particle size distribution of the suspension.

Methods of Measurement

1. Absorptiometric

Measurement of the optical density of the sample at a wavelength that provides maximum sensitivity for this type of determination. See Figure 13-2.

FIGURE 13-2 SPECTRONIC

When a plant using Carbon Filters has a carbon leakage, the only way of measuring the concentration of this suspension is by using an Absorptiometer that has been calibrated with varying concentrations of the same carbon material.

Although the presence of a haze in water does not always mean that the water is unfit for drinking, it can be regarded as visually offensive, and it definitely presents an optical problem if not a health hazard. Thus, it can be readily recognized that optical units are a more meaningful way of expressing this parameter, in order to assess the magnitude of the problem.

2. Turbidimetric

Measurement of the depth at which a metallic disc just fades out of view in a liquid. See figure 13-3.

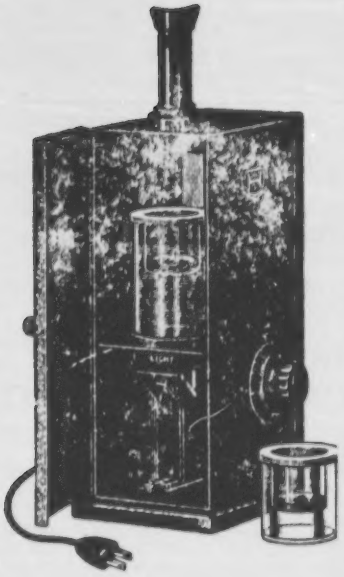


Figure 13-3 Hellige Turbidimeter

3. Nephelometric (Greek: Nephele-Cloud)

   a) Measurement of the intensity of scattered light by the particles in suspension. The usual angle for measuring the scattered light is at 90 degrees to the incident light. This method of measuring opacity is the most sensitive way of determining the concentration of suspended material in low turbidity treated waters. Instruments incorporating this principle are recommended for use at water plants, because they are the only ones that measure with great accuracy any water that has a very high clarity. Such instruments are very sensitive and can measure down to 0.03 FTU quite readily, and with great precision. See figure 13-4.

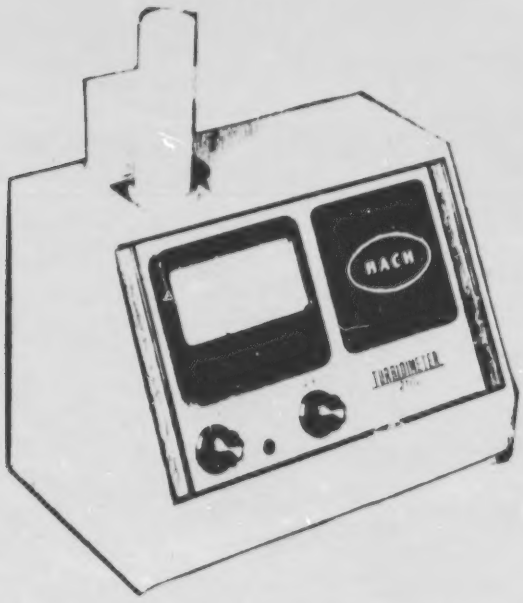


Figure 13-4 Nephlometer

Some plants that periodically have taste and odour problems usually incorporate carbon filters into their treatment system. At such plants, should the treated water become fouled by carbon leakage from a faulty filter the Nephelometric method cannot be used and a switch to the Absortiometric method becomes necessary in order to measure the carbon particles in suspension.

4. Hach 2100A Turbidimeter

a) The Hach 2100A Turbidimeter that has recently been evaluated by the Ministry of the Environment uses the Nepholometric principle. This instrument is reliable and performs with great accuracy, if determinations are carried out in the following manner. This method includes several important points not found in the manual issued with it.

b) *Important Points to Remember - in determining Turbidity with the Hach 2100 and Hach 2100A.*

(1) Check that the instrument is optically aligned with the template provided. If alignment is needed, call Technical Advisory Services. On no account should the Plant Technician or Operator try to do the job himself as this necessitates opening the back of the instrument and working near 1800 volts. This is extremely dangerous.

(2) The temperature of the instrument goes up when the instrument has been recently switched on. This causes the calibration point to slowly drift downward. An operating plateau is reached about 100 minutes after switching on the instrument.

(3) Always keep the range switch on 0 when using Model 2100 and on 1000 when using Model 2100A, or else the photo sensitive equipment could be damaged.

(4) Always rotate the range switch in a way that will avoid a lower scale than the sample requires coming into play. If this happens, the indicator needle hits full scale and the instrument goes out of calibration.

(5) Beware of de-gassing samples or covering the cell with greasy fingers.

(6) Always check the cell, using very low turbidity water to see how clean it really is.

(7) Standardize the instrument with newly precipitated Formazin Standard Solutions at all ranges. If adjusting is necessary, call Technical Advisory Services.

(8) Standardize calibration rod against Formazin.

(9) Never forget to use the cell riser on the 100 and 1000 FTU ranges.

(10) Never leave a sample in the instrument.

c) Operation Steps

(1) Standardize the instrument with the standards supplied by Hach.

(2) Check the cell for cleanliness with low turbidity preserved water (supplied by Technical Advisory Services).

(Calibrate as frequently as possible, especially after instrument has recently been switched).

(3) Fill the clean cell with the carefully stirred sample. Dry and polish the outside with Kimwipes. Place the cell in the instrument and cover it with the light shield.

(4) Set the range at which the reading is to be made and take a reading.

(5) Return the range to 0 on model 2100 and to 1000 FTU on model 2100A.

(6) Remove the sample and rinse the cell and replace it in the instrument.

SOLIDS

Total Solids

1. Definition

   The total solids of a sample consists of the sum of the weights of the visible solids, which include all the settleable and unsettleable solids, plus the weight of the (invisible) dissolved solids that are in solution.

2. Measurement

   a) The only accurate way of measuring the total solids of a sample is by the process of actually weighing a dried sample according to the following method:

   b) Apparatus Required:

      Porcelain Dishes, Drying Oven, Desiccator, Analytical Balance, and a 50 ml Pipette. (See Figures 13-5 and 13-6)

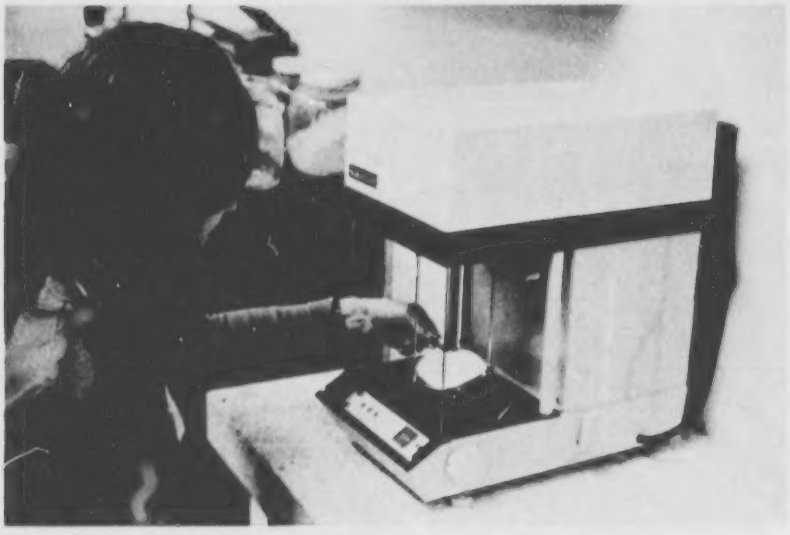


Figure 13-5 ANALYTICAL BALANCE

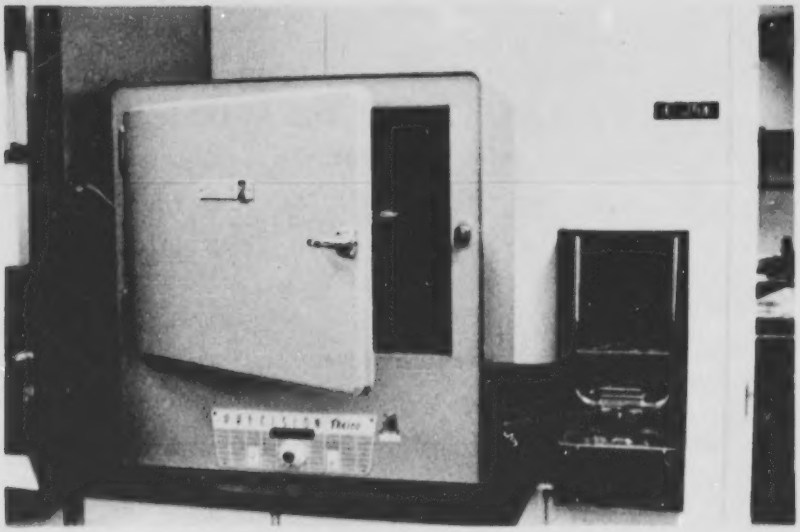


Figure 13-6 Drying Oven

3. Procedure

a) A clean porcelain dish is heated in an oven for two hours at 104°C.

b) It is then cooled in a desiccator for two hours* and weighed on an analytical balance to $\pm$0.0001 gram (W_1).

c) By Pipette, 50 mls of the well shaken sample is placed in it, and it is put to dry in a ventilated oven at 104°C. (This operation is best carried out at the end of the working day, so that the sample can dry undisturbed overnight).

d) The dried sample is then allowed to cool in the desiccator for two hours.*

e) It is then weighed again (W_2) to the same accuracy as before $\pm$0.0001 gram.

f) The total solids calculation is:

(i) $\frac{W_2 - W_1}{50} \times 1000$ g/l

OR

(ii) $\frac{W_2 - W_1}{50} \times 1000 \times 1000$ mg/l

* The cooling period is prolonged to 3 or 4 hours if there are several dishes in the desiccator cooling at the same time.

EXAMPLE 50 ml sample portion

Weight Porcelain dish (W_1) = 40,0000 g.

Weight Dish + Dried Residue (W_2) = 40,5403 g.

Total Solids = $\frac{W_2 - W_1}{50} \times 1000$

$= \frac{40,5403 - 40,0000}{50} \times 1000$

$= \frac{,5403}{50} \times 1000$

= 10.806 g/l.

To convert grams into milligrams multiply by 1000

∴ Total Solids = 10.806 x 1000

= 10806 mg/l

Suspended Solids

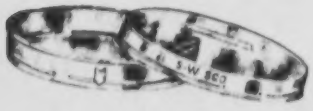
1. Measurement

a) The most accurate method that exists for the direct determination of suspended solids was developed in 1960, when the glass fibre filter first made its appearance on the market. It is known as the Glass Fibre Filter Method.

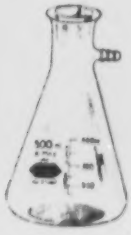
b) The method involves using a glass fibre filter of 0.45 micron pore size, and filtering as large an aliquot as both the size of the sample, and the concentration will allow. Using this method reduces the size of the error that sometimes arises owing to faulty technique, because the factor that is used to calculate the result on the basis of one litre of sample is very much smaller than the factor corresponding to the 50 ml aliquot that is used in the double dish method.

2. Apparatus Required

Glass fibre Filters, a Drying Oven, a Desiccator, an analytical Balance, a 100 ml Pipette, several large Petri Dishes, a Metal Ring (8.5 cm diameter and 4.5 cm deep), a Filter Funnel, a 2 litre Buchner Flask, a Source of Vacuum, and Square Tipped Tweezers. See figure 13-7.

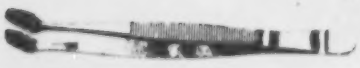


Petri Dish



Buchner Flask

Filter Funnel



Tweezers

Figure 13-7 Apparatus for Determination of Suspended Solids.

3. Procedure

a) Place a glass fibre filter in a funnel that is fitted to a Buchner Flask, which is connected to a source of vacuum.

b) Fill the funnel with distilled water and turn on the vacuum.

c) After about 15 seconds of sucking the filter dry, close the vacuum, and remove the filter with special square tipped tweezers, and place the filter in a clean large Petri dish.

d) Place the Petri dish in the oven and dry the filter for one hour at 104°C.

e) Place the Petri dish in a desiccator and cool for one hour.

f) Take the filter from the desiccator and weigh it (W_1 grams).

g) Place the filter in the funnel on the buchner flask, and place the metal ring centrally on it.

h) Pipette 100 mls of the sample onto the filter and turn on the vacuum slowly. Keep pipetting onto the filter any amount that the size of the sample and the concentration of the suspended solids in it will allow.

i) When all the sample has passed through the filter, wash the inside of the metal ring onto the filter then wash the filter (to free the dissolved solids in it) twice.

j) Remove the ring from its position on the filter and with the special tweezers take up the filter and place it in the Petri dish.

k) Place the Petri dish in the oven and dry the filter for one hour.

l) Remove the Petri dish containing the dried filter from the oven and place it in the desiccator. Allow it to cool for one hour. (If several filters are taken out of the oven and placed in the desiccator at this time, the cooling period will have to be prolonged).

m) Take the filter from the desiccator and weigh it again (W_2 grams).

n) Calculate the mg/l (ppm) of the suspended solids thus:

$$\frac{W_2 - W_1}{\text{sample aliquot}} \times 1000 = \text{g/l suspended solids}$$

EXAMPLE 100 ml sample portion (aliquot)

$W_1 = 0.4038$

$W_2 = 0.4459$

$$\text{Suspended Solids} = W_2 - W_1 \times 1000 \text{ (g/l)}$$
$$= \frac{0.4459-0.4038}{100} \times 1000$$
$$= \frac{0.0421}{100} \times 1000$$
$$= 0.421 \text{ g/l or } 421 \text{ mg/l (ppm)}$$

Note: g/l x 1000 = mg /l (ppm)

Dissolved Solids

The dissolved solids of a sample consist of Calcium and Magnesium soluble salts together with other soluble substances that have been picked up from the terrain through which the water has been flowing.

There are three methods of measurement, *method 3 being the least accurate:*

1. By using the Total Solids method as described previously, except that a filtered sample is used, instead of the sample as received.

2. Mathematically, i.e. subtracting the suspended solids figure as obtained by the glass fibre filter method from the result obtained by the total solids method.

3. Electrometrically, i.e. by measuring the conductance of the sample.

TASTE AND ODOUR

General

Taste and odour problems are usually caused by both organic and inorganic materials that have inadvertently entered the raw water source. When this happens, our first objective should be to identify the material that is giving rise to the problem and then close off or slow down its further entry into the water system. The next step is to try to eradicate any material that is residual in the system, by carbon filtration if the contaminant is organic, or by flocculation, and filtration if it is inorganic.

Method of Measurement

A panel of at least five non-smoking people should be selected, who have not eaten anything or drunk anything stronger than water for at least two hours. The location chosen should be free from all odours, and the panel should work individually, if space allows.

Procedure (See Appendix 1)

1. The following series of dilutions: 2,4,8,16,32, 64,128 and 256 should be made from the sample using odourless water (i.e. Carbon Filtered Tap Water).
2. Place 250 mls of the above dilutions in 500 mls clean stoppered flasks.
3. The diluted samples should be warmed to 60^{o}C, and starting with the highest dilution they should be passed around among the panel members; each member must shake the flask before trying to detect an odour.
4. The greatest dilution at which at least three members of the panel concur about the presence of an odour, should be taken as the Threshold Odour Number.

The procedure for the determination of taste threshold number is the same as the one for the odour threshold number, except that the dilutions are not warmed to 60°C, but are tasted at room temperature (70°F).

THRESHOLD ODOUR TEST

Purpose:

(1) to check on the odour quality of raw and treated waters

(2) to control odours in the plant

(3) to determine dosages of chemicals required for treatment

(4) to evaluate effectiveness of different treatment methods

(5) to determine or trace the source of contamination

Principle

Substances causing tastes and odours in water are present in such minute quantities and are of such varied nature that chemical analytical methods are not very reliable. Therefore one's own sense of taste and smell have been found to be the most suitable for detecting and measuring the odour quality of the water. Since the sense of smell is more convenient to use, it has become the basis of the "Threshold Odour Test" by which the odour intensity in the sample of water is measured.

Threshold odour number represents the number of times or the dilution ratio to which a sample of an odour-bearing water must be diluted with odour free water to reduce the odour so that it is just detectable.

Apparatus Required for the Test

6 to 8	500 - ml Erlenmeyer flasks with ground glass stoppers (≠32)
2	thermometer, 0^{o} - 110^{o} C
1	250 - ml graduated cylinder
1	100 - ml " "
1	50 - ml " "
1	25 - ml " "
1	10 - ml or 5 - ml graduated pipette
1	large electrical hot plate
1	water bath
1	odour-free water generator

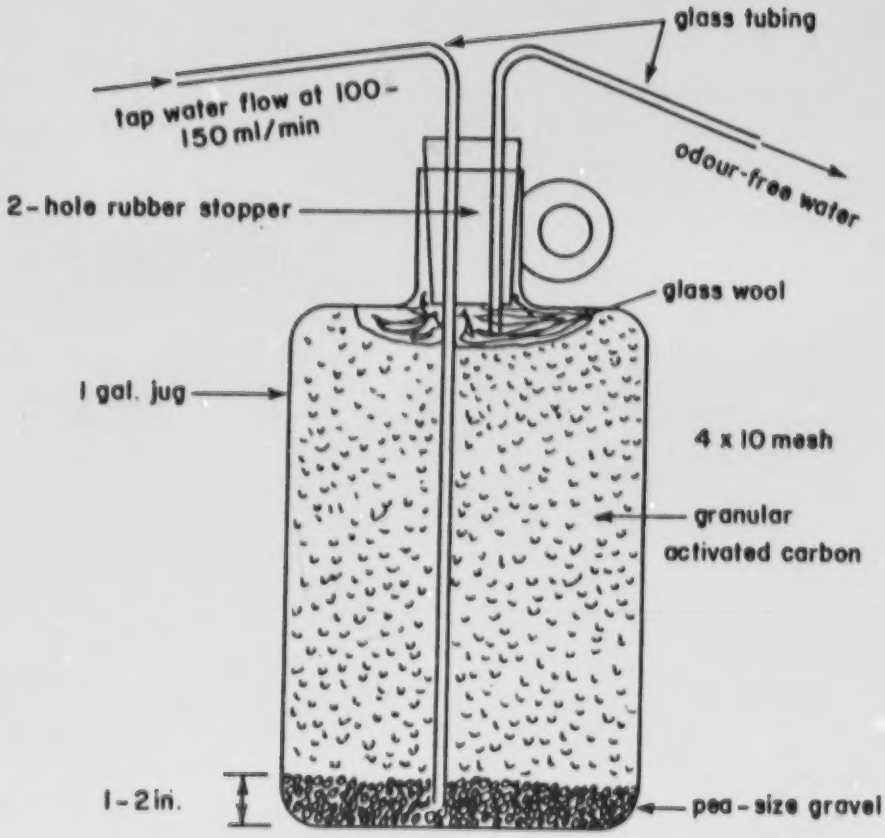


FIGURE 13-8 ODOUR-FREE WATER GENERATOR

Preparation of Odour-Free Water

To conduct threshold odour and taste tests, an adequate supply of odour-free water should be available. Odour-free water is required for preparing the dilutions of the odour-bearing samples, for reusing all glassware free of odours and for use as a blank in the test.

Odour-free water should be prepared as needed because it will absorb any odours that may be in the room. Most tap waters are suitable as sources for the preparation of odour-free water. This is done by passing tap water through the odour-free generator at the rate of 0.1 liter per minute. This is approximately 20 minutes of contact time with the carbon.

Procedure

Determine the approximate range of threshold odour number

1. Add 200 ml, 50 ml, 12 ml, and 2.8 ml of the sample water to each separate glass-stoppered Erlenmeyer flasks. Each flask should be numbered.

2. Add odour-free water to make a total volume of 200 ml in each flask.

3. Add 200 ml of odour-free water to another glass stoppered flask which will be used as the reference for comparison.

4. Heat all of the flasks to 60° C in the water bath or on the hot plate. (Considerable time can be saved by preheating the odour-free water to 60° - 65° C)

5. Shake the flask containing the odour-free water. Remove the stopper and sniff the vapours.

6. Do the same with the flask containing the least amount of odour-bearing water (undiluted sample) and note whether it has an odour and if so, describe what type.

7. If the odour can be detected in this flask then more dilute samples must be prepared.

8. If the odour cannot be detected in the first diluted sample, repeat this procedure —— first sniffing the flask with the odour-free water —— with the flask containing the next higher concentration of the odour-bearing water.

9. Continue this process until the odour is clearly detected.

Determine the actual T.O.N. of the odour-bearing water.

1) Based on the results obtained in the preliminary test, prepare a set of dilutions using the following table as a guide.

DILUTIONS FOR VARIOUS ODOUR RANGES			
Sample Volume in Which the Odour First Noted			
200 ml	50 ml	12 ml	2.8 ml
Volume of Sample to be Diluted to 200 ml			
200 ml	50 ml	12 ml	
140	35	8.3	2.8 ml
100	25	5.7	2.0
70	17	4.0	1.4
50	12	2.8	1.0

2) Dilute each sample of odour-bearing water to 200 ml with odour-free water.

3) Add 200 ml of odour-free water to two or more flasks to be inserted into the series as a reference and a blank for comparison.

4) Mark each flask with a number or a letter.

5) Heat all the flasks to 60° C and then arrange them so their odour is unknown.

6) Shake the flask containing the odour-free water. Remove the stopper and "sniff" the vapours.

7) Take up the other flasks one by one, remove the stopper and "sniff" the vapour comparing each one with the one containing the odour free water.

8) Record the results for each flask as "positive" (+) if an odour was observed and negative if no odour was observed.

Example

code	1	2	3	4	5	6	7
ml sample	12	0	17	25	0	35	50
Response	-	-	-	+	-	+	+

9) The dilution containing the smallest volume of odour bearing water which gives a positive reaction is the threshold odour number (T. O. N.). In the above example, the first detectable odour occurred when 25 ml of odour-bearing was diluted to 200 ml with odour-free water.

Therefore $T.O.N. = \frac{200}{25} = 8$

'he following table gives the dilutions and their corresponding T. O. N. values

THRESHOLD ODOUR NUMBERS CORRESPONDING TO VARIOUS DILUTIONS

Sample Volume Diluted to 200-ml	T. O. N.	Sample Volume Diluted to 200-ml	T. O. N.
200	1	12	17
140	1.4	10	20
100	2	8.3	24
70	3	5.7	35
50	4	4	50
40	5	2.8	70
35	6	2.	100
25	8	1.4	140
20	10	1.0	200

Precautions

1. Selection of persons
2. Selection of test area where the tests are being conducted

3. Cleaning of the glassware
4. Precautions in making dilutions
5. Elimination of residual chlorine in the treated water

References

(1) STANDARD METHODS for the Examination of Water and Wastewater, 13th Edition. APHA AWWA WPCF 1971 pp 248-254

(2) Taste & Odour Control in Water Purification West Virginia Pulp & Paper Co. (Chemical Division) 230 Park Avenue, New York, N.Y. 10017 (1966). This publication is available on request from Standard Chemical Limited
60 Titan Road,
Toronto M8Z 1J8

SUBJECT:

TOPIC: 14

PROCESS CONTROL TESTS

- DPD Method
- Orthotolidene Test
- Amperometric Titration Method

OBJECTIVES:

The trainee will be able to:

1. demonstrate and carry out the procedures for determining the chlorine residual using the DPD method with the Nesslerizer and comparator;

2. determine the chlorine residual of a given sample using the orthotolidene test;

3. Recall the principle of operation of the Amperometric titrator.

DPD METHOD

Principle of the Method

Research in chlorine chemistry has resulted in the development of a very simple procedure for the determination of its free and total residual. With the new method differentiation between the combined forms of chlorine is also possible using the DPD indicator. The test has a high precision and accuracy and when properly used it can be an excellent aid in the control of chlorine residual at a water treatment plant.

A good feature of the Lovibond Comparator method lies in its use of compressed tablets which are convenient to handle, more stable than the DPD solution, and is a procedure of exceptional simplicity. In a recent investigation by the Water Research Association this method was judged the BEST COLORIMETRIC METHOD for the measurement of chlorine and chloramines in water.

Equipment and Reagents Required

1. DPD tablets for Comparator and Nesslerizer
   a) Nos. 1 & 3 together for total chlorine residual.
   b) No. 1 for free chlorine.
2. Comparator with Standard Lovibond Discs
   a) 3/40A disc covers the range 0.1 to 1.0 mg/l chlorine.
   b) 3/40B disc covers the range 0.2 to 4.0 mg/l chlorine.

   These discs require 13.5 mm. cells or test tubes. A dulling screen must be used.

3. Nesslerizer with Disc

NDP covers the range 0.05 to 0.5 mg/l. This disc must be used with a dulling screen and 50 ml tubes.

Procedure

1. Compactor

a) Determining Total Chlorine Residual

(i) Place a 13.5 mm cell or test tube containing sample only in the lefthand compartment, behind the colour standards of the disc.

(ii) Rinse a similar cell with the sample, and fill the cell or tube up to the mark with it.

(iii) Into this cell or tube drop one No. 1 and one No. 3 tablet (or one No. 4 tablet, which is No. 1 and No. 3 combined.

(iv) Allow tablets (or tablet) to disintegrate until effervescence ceases.

(v) *Mix rapidly* to dissolve the remains of the tablet.

(vi) Place the cell in the righthand compartment of the Comparator.

(vii) *After 2 minutes*, match the cells by holding the Comparator facing a good source of diffused north daylight and *revolve this disc until the correct standard is found. NEVER LOOK INTO THE SUN.*

(viii) The figure shown in the indicator window represents mg/l of *total chlorine residual* present in the sample.

b) Determining of Free Chlorine Residual

(i) Prepare tubes as outlined above for total chlorine residual, one "blank" tube and one with just a few drops of sample.

(ii) To the tube with sample, add one No. 1 tablet only.

(iii) After disintegration, add water up to mark, and

(iv) Mix as before and match at once. This gives *free chlorine residual.*

Note: It is permissible to determine TOTAL CHLORINE on the same sample by continuing as follows: add one No. 3 tablet, mix and stand for 2 minutes. The colour then read off represents *total chlorine residual.*

c) Determining Combined Chlorine Residual

Total Chlorine Residual - Free Chlorine Residual = Combined Chlorine Residual Value.

2. Nesslerizer

Follow exactly the same procedure for the Comparator, with the following exceptions:

a) Use 50 ml instead of 10 ml.

b) Use special Nesslerizer DPD tablets.

Note: *It must be emphasized that the readings obtained by means of the B.D.H. Lovibond Nesslerizer and disc are only accurate provided that Nesslerizer glass is used which conforms to the specification employed when the discs are calibrated, namely, that the 50 ml calibration mark shall fall at a height of 113 ± 3 mm, measured internally.*

3. False Colour due to Interferences

a) The only interfering substance likely to be present in water is oxidized manganese from potassium permanganate in those water plants that use it for taste and odour control.

b) Test the unchlorinated water for colour development and use as a Blank.

c) *All glassware used must be very thoroughly rinsed after making a test, since only a trace of potassium iodide will cause chloramine colour to develop. Handling the tablets should be avoided. By shaking one tablet into the bottle top it is a simple matter to use the top for conveying the tablet to the Comparator cell or Nessler tube.*

ORTHOTOLIDENE TEST (OT)

General

The orthotolidene test (OT) is used to determine the presence of chlorine residuals in the water. The water is tested for total chlorine residual 15 minutes or longer after chlorination by adding the sample to the OT reagent in a glass tube or glass container. A yellow colour in the sample indicates the presence of a chlorine residual. The deeper the yellow the greater the residual. A lemon yellow colour indicates a safe residual for drinking water.

An approximate free chlorine residual can be determined only when the temperature of the sample is at or very near freezing. The colour caused by free chlorine residuals develops instantly at water temperatures near freezing after the OT reagent is added to the sample. Colour caused by the combined residual develops more slowly, and normally takes up to 5 minutes. The speed of colour development of combined residuals is increased with higher water temperatures.

It is possible that in highly alkaline waters (quite rare in Ontario) a blue tinge may result instead of the yellow colour. This may be corrected by adding an excess amount of OT reagent. Since the reagent is acidic, it will neutralize the excess alkalinity in the water sample. It should be noted that adding too much OT reagent introduces inaccuracies in the residual reading.

The OT method is an old one dating back to 1914, and is still in use in many plants. It has two disadvantages:

1. The super-sensitivity of the chemical causes high intensity colour development so that a chlorine residual cannot be measured accurately above 1 ppm concentration.
2. Free chlorine residual determination only gives an approximate result; ie. you get an idea of its range. The OT method must not be used when an accurate free chlorine residual is required.

To add to this, iron, manganese and nitrites can cause a false colour. The OT method is slowly being replaced by the DPD and the Amperometric methods both of which will be discussed in this workshop.

Procedure for Total Chlorine Residual

1. Pour the required amount of OT reagent into the Nessler tube, Colorimeter cell or other container. Use
   - 0.5 ml OT reagent in 10 ml cell
   - 0.75 ml OT reagent in 15 ml cell
   - 5.0 ml OT reagent in 100 ml cell

   and similar ratios for other volumes.

   Note: *OT reagent should not be kept longer than 6 months. It should be stored in amber-coloured bottles, kept out of direct sunlight and should not be subjected to high or low temperature. Fresh supplies of OT reagent may be obtained free of charge from the M.O.E. Laboratories.*

2. Adjust the temperature of sample to between 15°C and 24°C (quickly) using warm or cold water.

3. Add sample to the cell or tube up to the mark.

4. Mix solution.

5. About 5 minutes after maximum colour develops, a slight fading begins; therefore, samples containing combined chlorine should be read within 5 minutes and should, preferably, be allowed to develop colour in the dark.

Free Chlorine Residual Test

1. An orthotolidene *flash test* modification for free chlorine residual performed near 1°C (34°F) or freezing point minimizes the effect of chloramines and their reaction with orthotolidene to produce a yellow colour. Temperature is a critical factor. The sample should be near the freezing point to obtain meaningful results. This is in direct contrast to the OT procedure for combined chlorine residual where the temperature of the sample should be around 20°C (68°F).

2. Although oxidized manganese affects the test results, slow-acting interfering substances, nitrites and oxidized iron, do not have a significant influence. The flash test has the disadvantage of requiring the *reading of colour within 5 minutes*.

3. *This method is suitable for estimating only.*

4. Procedure for Flash Test

   a) Cool the sample quickly to within one degree of the freezing point.

   b) Add the appropriate amount of orthotolidene reagent that is adequate for the cell or Nessler tube.

   c) Fill the cell or tube up to the mark with the sample.

   d) Place it in the comparator or Nesslerizer and read immediately.

AMPEROMETRIC TITRATION METHOD

General

The most accurate methods of measuring free and combined chlorine residuals is through oxidation-reduction titration procedures. Such methods require the use of internal indicators or electrometric devices employing a suitable electrode system to show when reactions are completed. Amperometric titrators employing rotating platinum electrodes have been developed for such purposes. See Figure 11-1, page 11-5.

Phenylarsene oxide is the reducing agent normally used as the titrating agent. It reacts with free chlorine residuals at pH 6.5 to 7.5 in a quantitative manner.

By conducting a two-stage titration, with the pH adjusted at about 7 and then at about 4, it is possible to measure separately free chlorine residuals and combined chlorine residuals.

Titrator - Principle of Operation

Titration is a method used to determine the concentration of a substance in a solution. This is accomplished by adding the smallest amount of a reagent (of known concentration) required to cause a neutralizing effect, in reaction with a known volume of the test solution. A graduated vessel (or burette) is used to add the reagent to the known volume of test solution until the chemical reaction between the two is completed. The point of completion is indicated by either (a) adding an indicator dye and watching for a change in its odour or (b) stopping at a predetermined end point on a pH meter or microammeter.

A direct current potential is impressed across two nodal metal electrodes immersed in a measuring cell containing the sample of the solution to be tested. Any

flow of current between the electrodes is directly proportional to the quantity of halogen (such as chlorine, bromine, or iodine) in the sample. The presence of a current is indicated on a microammeter at the top of the instrument.

A reagent (also called a titrant) is added in small doses to the sample, and reacts chemically with the chlorine present in the solution, thereby neutralizing a portion of the chlorine. As more titrant is added, more chlorine is "removed", causing the current flowing between the electrodes to diminish as indicated by the microammeter pointer moving down the scale. Finally, sufficient titrant is added to react with all the chlorine, and no further decrease in current is possible. This is called the *end point*.

The amount of chlorine residual present in the test solution is determined by noting the number of millilitres of titrant used to attain the end point. Then:

mg/l of chlorine = mls of titrant that have been used.

Procedure

1. Filling the Burette

   Make sure the titrant (phenylarsene oxide solution) fills to the zero mark.

2. Titration of Free Chlorine Residual

   a) Fill the solution jar with 200 ml of sample.

   b) Add 1 ml pH 7 buffer solution.

   c) Fill the microburette with the titrant (phenylarsene oxide solution) to the zero mark.

   d) Titrate by adding phenylarsene oxide solution and observe current changes on the microammeter. As long as addition of phenylarsene oxide produces a definite decrease in current, free chlorine residual is present.

e) The end point is just passed when a very small increment of phenylarsene oxide no longer causes a decrease in current.

f) The burette is then read and the last increment of titrating solution is subtracted from the reading to give a value representing the free chlorine residual.

3. Titration of Total Chlorine Residual

a) To the sample remaining from the free chlorine titration add 1 ml potassium iodide solution and then 1 ml pH 4 buffer solution IN THAT ORDER.

b) Titrate with phenylarsene oxide solution to an end point, just as above for the free chlorine residual. It is most convenient NOT to refill the burette but simply to continue the titration.

c) After concluding the titration and having found the end point, subtraction of the last increment again gives the amount of titrating solution actually used in reaction with the chlorine.

d) If the titration was continued without refilling the burette, this figure represents the total chlorine residual. Substracting the free chlorine residual from the total gives the combined chlorine residual, or

Total Chlorine Residual - Free Chlorine Residual = Combined Chlorine Residual

Note: It is essential to wash the apparatus and sample cell thoroughly to remove iodide ion and acetate buffer after this determination, in order to avoid inaccuracies if the titrator is subsequently used for free available chlorine determination.

e) If desired, the determination of the total chlorine residual and the free chlorine residual may be made on separate samples. If only the value for total chlorine residual is required, it is permissible to treat the sample immediately with 1 ml potassium iodide solution followed by 1 ml pH 4 buffer solution. The titration is carried out with phenylarsene oxide solution as described on page 14-8 (2(c)).

Monochloramine and Dichloramine Differentiations

It is often desirable to differentiate between the monochloramine and dichloramine portion of the combined chlorine residual in a sample solution. This differentiation is accomplished in the following manner:

1. Perform the procedure outlined in Procedure for the Titration of Free Chlorine Residual. Note the reading in ppm (free chlorine).
2. Add 4 to 5 drops of potassium iodide, 5% solution to the sample jar. If monochloramine is present, the ammeter pointer will deflect to the right.
3. Titrate to the "end point"; note the reading in ppm.
4. Add 1 dropper of pH 4 buffer solution and add 1 dropper of potassium iodide, 5% solution to the sample jar. If dichloramine is present, the ammeter pointer will again deflect to the right.
5. Titrate to the "end point"; note the reading in ppm.

The difference between the readings obtained in step 1 ("free" chlorine) and step 3 preceding, represents the monochloramine component.

The difference between the readings obtained in step 3 and step 5 represents the dichloramine component.

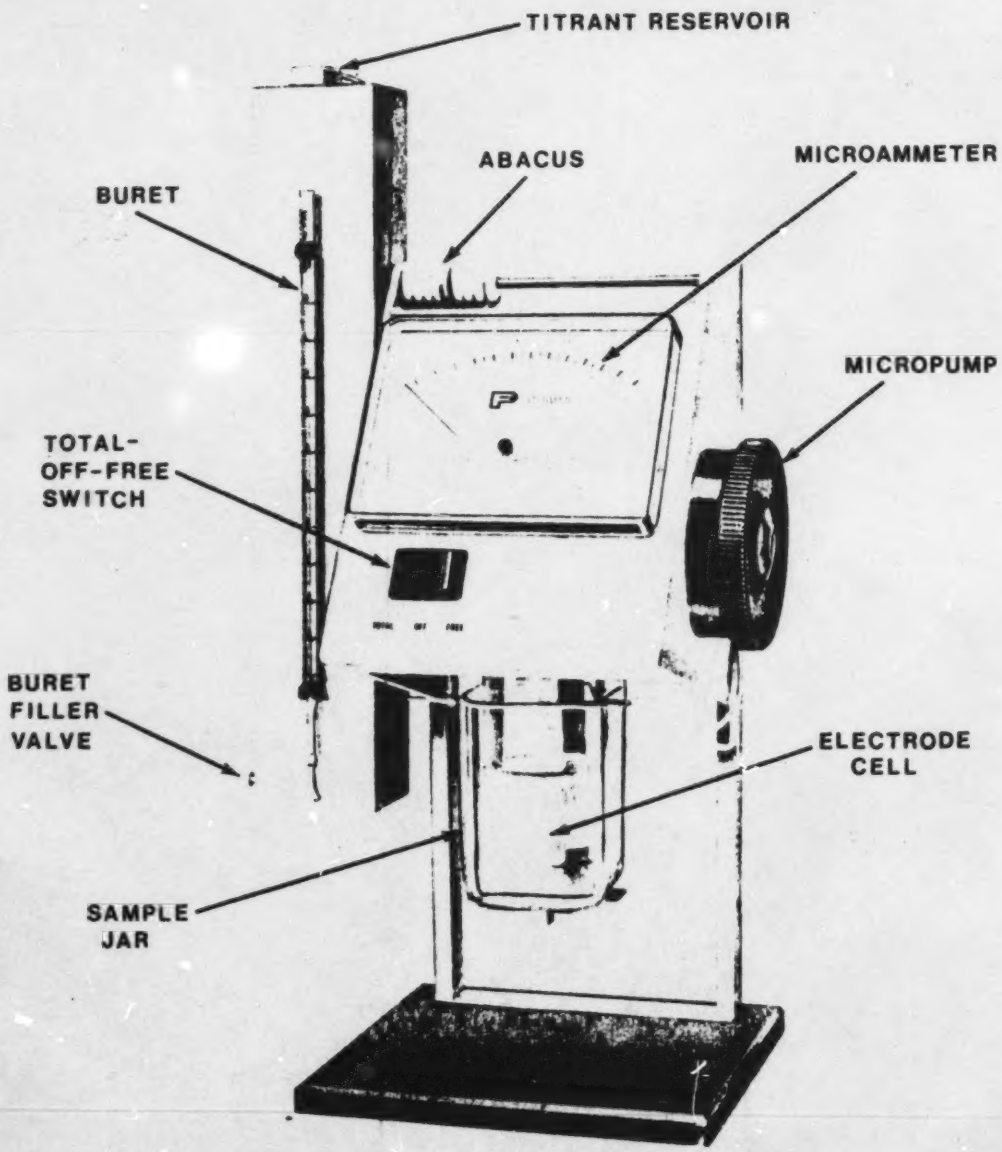


Fig. [illegible]-1. Amperometric Titrator
(Courtesy Fischer & Porter)

GLOSSARY OF TERMS

The following definitions are intended only as aids in the study of this manual.

absorption -
The taking up of one substance into the body of another.

ABS -
Abbreviation for Sodium alkyl benzene sulfonate.

adsorption -
(1) The adherence of a gas, liquid or dissolved material on the surface of a solid.

(2) A change in concentration of gas or solute at the interface of a two-phase system.

aeration -
(1) The bringing about of intimate contact between air and a liquid by one or more of the following methods:

a. spraying the liquid in the air,
b. bubbling air through the liquid,
c. agitating the liquid to promote surface absorption of air.

(2) The supplying of air to confined spaces under nappes, downstream from gates in conduits, etc. to relieve low pressures and to replenish air entrained and removed from such confined spaces by flowing water.

(3) Relief of the effects of cavitation by admitting air to the section affected.

air gap -
The distance between the lowest opening of a pipe supplying water to a tank or plumbing fixture and the flood-level rim of the receptacle.

algae -
Tiny plants, usually living in water and often green in colour.

algicide -
Anything applied to kill or control algae.

anionic -
Relating to negatively charged ions.

aquifer -
Porous, water-bearing formation of rock, sand, or gravel.

artesian aquifer -
An aquifer where the water is under pressure and will rise to a higher elevation if afforded an opportunity to do so.

backflow -
The backing up of water through a conduit or channel in the direction that is opposite to normal flow.

bacteria -
Single-celled microscopic plants living in soil, water, organic matter or the bodies of plants or animals.

backwash -
The method used to clean filter media by reversing the water flow.

booster station -
A pumping station in a water distribution system, used to increase the pressure in the mains on the discharge side of the pumps.

chlorine demand -
The difference between the amount of chlorine added to a water or wastewater and the amount of chlorine residual left after a certain length of time.

chlorine residual -
The amount of chlorine still left available after a certain length of contact time.

clear well -
Reservoir for storing filtered water.

coagulants -
In water and wastewater, chemicals used to thicken finely divided suspended solids into groups for easy removal.

coagulation -
In water and wastewater treatment, the destabilization and initial aggregation of colloidal and finely divided suspended matter by the addition of a floc-forming chemical or by biological processes.

coliform -
A group of bacteria normally living in the intestines of man and animals and are also found elsehwere in nature. They are pollution indicators in water supplies.

colloidal -
Too finely divided to settle; requiring coagulation, biochemical action, or membrane filtration for removal.

combined chlorine residual -
The concentration of chlorine combined with ammonia as chloramine or as other chloro-derivitives, yet is still available to oxidize organic matter or carry on disinfection of water.

cone of depression -
A cone-shaped hollow made in a water table as water is drawn from a well.

contact basin -
A basin used to put water or wastewater in contact with chemicals or other materials; for example, a chlorine contact chamber.

contamination -
The presence of microorganisms, chemicals, or wastes that make water unfit for use.

diatomaceous earth -
A fine soil made up mostly of the skeletal remains of diatoms.

diatoms -
Single-celled microscopic algae that grow in or on water and have skeletons of silica.

disinfection -
Destruction of disease causing microorganisms by physical or chemical means (chlorination or boiling of water).

distribution system -
A system of piping, canals, and associated equipment used to distribute a water supply to consumers.

drawdown -
The lowering of a water level in a well or a tank.

effluent -
In wastewater treatment, wastewater or other liquid, partially or completely treated or in its natural state, flowing out of a reservoir, basin, treatment plant, or industrial treatment plant, or part thereof

enzyme -
A protein that promotes a chemical reaction, enabling it to continue at body temperature.

filter cake -
Dewatered sludge or sediment.

filter media -
The material through which water or wastewater is filtered.

filtration -
The process of passing a liquid through a filter to remove suspended solids.

floc -
Small jelly-like masses formed in a liquid by adding a coagulant.

flocculation -
The collection of coagulated suspended solids into a mass by gentle stirring.

flocculation aids -
Materials added to liquid to form flocs.

flocculator -
Mechanical equipment used to encourage the formation of floc in liquid.

hydrologic cycle -
The movement of water from the atmosphere to the earth and back to the atmosphere through precipitation, infiltration, storage, transpiration, evaporation etc.

hydrolysis -
A chemical process of decomposition using the addition of water. Also, the process solid matter goes through to become liquid.

indicator bacteria -
Coliforms that point to the presence of intestinal pathogens.

influent -
Water or wastewater flowing into a treatment plant or any of its units.

injection wells -
Wells created to recharge groundwater.

inorganic -
Made of matter that is not plant or animal.

ion exchange
A chemical process in which ions from two different molecules are exchanged.

ionizing -
Creating ions by adding electrons to, or removing them from, atoms or molecules.

iron bacteria -
Bacteria that use iron as food and discharge its compounds in their life processes.

leaching -
Percolating liquid through soil or other solids to remove the soluble ingredients.

metabolism -
The process in which food is used and wastes are formed by living matter.

MF -
Membrane filter (used in bacteriological lab test)

microbes -
Microscopic organisms, especially pathogenic bacterium.

micro-organisms -
Minute organisms, either plant or animal, invisible or barely visible to the naked eye.

MPN -
Most PROBABLE Number (used in bacteriological lab test).

nutrient -
Food for the growth of organisms.

organic -
Made of matter that is plant or animal.

ozonization -
The act or process of charging or treating with ozone. Also, the conversion of oxygen into ozone. Used for disinfection purposes.

pathogenic -
Disease-producing bacteria.

permeable -
Having pores or openings that permit liquids or gases to pass through.

pH -
The measure of the acid/alkaline balance, expressed on a scale of 0 to 14, with 7 being neutral; 7 to 0 increasing acidity, and 7 to 14 increasing alkalinity.

pressure head -
A measure of the pressure exerted by a fluid.

pseudomonad -
Short rod-shaped bacteria, some of which live on dead or decaying organic matter, or cause disease.

pumping level -
The height where water stands in a well during pumping.

reducing agent -
A substance that causes the loss of an electron.

retention time -
Detention time; the length of time that water or wastewater is held in a unit for any treatment.

septic -
Anaerobic (decomposition without oxygen).

spores -
Walled, single to many-celled reproductive bodies of microorganisms, able to produce new organisms directly or indirectly.

staining -
Colouring specimens for microscopic study. Also, colouring or discolouring anything.

static level -
The height of a water surface when groundwater is not being removed.

supernatant -
The liquid standing above a sediment. In sludge digestion, the liquid standing between the sludge at the bottom and the scum at the top.

surface water -
All water found on the surface of the earth.

suspended solids -
(1) Solids that either float on the surface of, or are in suspension in, water, wastewater, or other liquids, and which are largely removable by laboratory filtering.

(2) The quantity of material removed from water or wastewater in a laboratory test, as prescribed in "Standard Methods for the Examination of Water and Wastewater" and referred to as non-filterable residue.

titration -
The method finding how much of something is in a solution by measuring how much of something else is needed to cause a chemical change.

total solids -
The sum of dissolved and undissolved constituents in water or wastewater, usually stated in milligrams per litre.

transpiration -
The process by which plants return water to the atmosphere.

turbidity -
A condition in water caused by suspended matter; murkiness.

volatile solids -
The quantity of solids in water, wastewater, or other liquids, lost on ignition of the dry solids at 550°C.

water hammer -
Loud blows caused by moving water against the sides of its containing pipe.

watershed -
An area that drains into a particular body of water or water course.

weir -
A dam or enclosure in water or wastewater used to raise the water level or change the direction of its flow; with notches or a crest, it measures the flow.

well head -
The top of the well.

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